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EVALUATION OF PREDICTABILITY OF QUARTZ-CRYSTAL OSCILLATORS AND --ETC(U)
JAN 81 L G CHARRON, R T CLARKE MIPR-HC1001-8-40079
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EVALUATION OF PREDICTABILITY OF QUARTZ-CRYSTAL OSCILLATORS AND OTHER DEVICES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Data were collected over varying intervals for several types of devices (quartz-crystal, rubidium, cesium beam oscillators and hydrogen maser) and compared to NAVOBSY USNO MC. An ARIMA and several polynomial models for prediction purposes were evaluated. It is concluded that very simple prediction methods can suffice in maintaining a timing system.

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EVALUATION OF PREDICTABILITY OF QUARTZ-CRYSTAL OSCILLATORS AND OTHER DEVICES

FEBRUARY 1981

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INTRODUCTION

The work to be discussed in this report has resulted from the following:

a. The recent discovery that Autoregressive Integrated Moving Average (ARIMA) models can be applied in the representation of the statistics of clock behavior, and that this can lead to a better separation of purely random from systematic clock noise;

b. The desire to replace cesium beam atomic clocks with less expensive devices in those applications where frequent comparisons with an external reference are possible; and

c. The recent availability of superior quartz crystal clocks and microprocessors at relatively low cost.

The use of ARIMA routines for clock modelling had originally been proposed by Barnes (reference 1). At that time, it was not believed to be a practical model because of the extraordinary precision with which the higher coefficients had to be determined in order to achieve acceptable results. The user of higher order polynomials for extrapolation purposes also has this difficulty. In both cases the available data simply does not allow determination of coefficients. This inability produces a compounded effect as extrapolation time goes beyond a few days. In time, even a third power polynomial as a representation of a frequency drift is useless in the case of cesium clocks unless the drift is based on several months of data. However, Percival (reference 2) has showed that for shorter intervals which are important in most practical applications it is not necessary to use such complicated procedures. The question then arises whether these newer predicting models will not allow an extrapolation of quartz crystal clocks for a few days in a simple and reliable manner. For a general discussion of the problem in separation of systematics from purely random (white) clock noise, see reference 3 and particularly figure 3 in reference 4.

The second issue, the replacement of expensive clocks, has also been considered previously. Current digital techniques and, particularly, the availability of inexpensive microprocessors now necessitate consideration of replacing hardware phase-lock loops with processor-controlled phase-steppers. Once data has been obtained from an oscillator connected to an external reference, digital filtering offers a sophisticated way of extrapolating beyond that data whenever the external reference is unavailable. For a general introduction to digital filtering, see reference 5.

The principal idea of using ARIMA models for this purpose is explained on p. 380 of reference 4. An ARIMA model (p,d,q) is a model with p regression and q moving average coefficients in the representation of the d-th differences of clock errors.

Suppose we represent these second differences in time (this yields a stationary time series, in contrast to the series of frequencies which usually exhibit drifts) by a linear difference equation such as:

$$z(t) = \sum_{i=1}^{p} \emptyset_i \cdot z(t-i) + \sum_{j=1}^{q} D_j \cdot a(t-j) + D_0 + a(t)$$

where the Ø's represent regression coefficients and the D's smoothing coefficients. The a's then represent the purely random part of the noise, i.e., the one-step advance prediction errors. The D_0 term (if it can be determined with sufficient confidence) is the systematic drift. Considering the purpose of this investigation, i.e., a study of the feasibility of using simple routines in field applications, it is noteworthy that after considerable experimentation with different choices of models and parameters it has become obvious that the simplest model, the ARIMA (0,2,1) with a coefficient of 0.75 as smoothing parameter is best for the purpose desired. The criteria used was that of a least square solution. In no case has a drift coefficient been included. The above equation therefore reduces to:

$$z(t) = -0.75 \cdot a(t-1) + a(t)$$

where the z(t) are the second differences of oscillator phase.

Another general comment should be made. For several years, it has been a common complaint that system designers could not relate to the stability measure which is most commonly used, the two-sample (Allan) variance. Indeed, as pointed out in reference 2, the use of this measure is not without problems. While the two-sample variance (and its square root, which corresponds to a standard deviation) is very simple to obtain, it is not completely insensitive to the presence of noise concentrated in narrow (Fourier) spectral regions; i.e., it is a measure which depends on the presence of a power low-noise spectrum. In contrast, the prediction errors obtained in this report are by themselves a measure of clock performance which is completely independent of any theory. It depends only on the choice of the prediction model. In this way, we obtain a measure which gives the designer exactly what is needed in any practical application.

DISCUSSION OF MEASUREMENTS

Table 1 lists the devices for which measurements were made using the data acquisition system (DAS) of the U.S. Naval Observatory (USNO) which was described by Putkovich (reference 6). [Specifications for the URQ10 and the Disciplined Time Frequency Oscillator (DTFO) are given in Appendix A. Specifications for the other devices are available in the manufacturers' manuals.] In this system, a matrix of clock starts against clock stops is measured with a time interval counter (HP5360 Computing Counter) with a resolution of 100ps. The measurements are performed every hour and form the basis for all time scale computations. The main advantage of this system is that the measurements, since they are time interval measurements, are strictly linear and are not plagued by nonlinearities of phase meters, etc. However, if 5MHz signals are used directly and the zero cross-overs are adopted as time markers, cycle ambiguities, of 200ns may exist. This is of no concern in the case of atomic clocks, but crystal clocks exhibit large frequency (rate) differences and the cycle adjustments cannot always be made unambiguously. As a consequence, only the 1 pps measurements are considered completely authoritative for the crystal clocks. This problem is peculiar to the data collection method and not at all representative of a real-life situation where code generators would be driven from the oscillators. After adjustment for cycle slips and other discontinuities, the value of 0000 UT has been used in the various solutions.

In some cases, there have been periods when it became obvious that the clock under test had suffered a disturbance (such as breakdown of laboratory temperature control). Such obviously disturbed periods for any clock have been excluded from analysis since the extrapolation of precise time measurements would not be representative of the capability of that clock. Figures 1 through 15 present UTC (USNO, MC) minus UTC (device).

The prediction errors have all been computed as the root mean square (rms) difference between a specific model prediction and the actual clock error as measured after the fact. These values, as well as the number of samples upon which they were based, are presented in tables 2 through 19. For these purposes, it is clear that the confidence in the prediction errors so determined will increase the longer the total data run.

Figures 16 and 17 are plots of the rms error versus prediction lead time for the shortest and longest calibration interval as determined by the ARIMA model for the URQ10 crystal oscillator and the HP236 rubidium. These are graphic representations of the data contained in tables 4 and 8. As anticipated, discontinuities are introduced when the number of sample intervals change. An extreme case is seen for URQ10 for the calibration interval of 56 days; between days 25 and 26 the number of sample intervals changes from 7 to 8.

In general, one can see from the tables that prediction errors decrease as the calibration interval increases. However, in all cases one can observe that there is a definite limit beyond which the prediction errors do not improve with longer calibration intervals. At this point, it would be necessary to change models. In the case of cesiums, at least, reference 2 gives several examples of (1,2,1) and (0,2,2) models which give very small prediction errors for 64 days. In the context of this investigation, however, direct comparability is judged the most important goal and the most interesting lead times for practical applications will be short ones.

The quality of the clock considered is directly given by its predictability. However, the manner in which the prediction errors decrease both with an increase in calibration interval and with an increase in lead times is much influenced by the model chosen. Overall, the simple (0,2,1) ARIMA model does best. But the difference with a linear extrapolation is not great. The higher power polynomials are all very poor except for Oscilloquartz #51 where we have strong indication that a third power model is best for long-lead times.

An example of the simplest possible oscillator included in the project is a watch crystal ($10 per unit), identified as Quartzmatic #1 (table 19). The factor of over 1000 by which this oscillator performs worse than any of the others is partially explained by the fact that there is no temperature control or compensation. This example is also interesting for the degree to which the higher power extrapolations degenerate for short calibration intervals. The signal-to-noise ratio is too poor to allow any but the simplest predictions for such short calibrations.

CONCLUSIONS

From the data presented, it is concluded that very simple prediction methods will suffice in maintaining a timing system during interruptions of the linkage with a timing reference. Clocks comparable in quality with the

Oscilloquartz units or the DTFO allow accuracies of about 1 microsecond over a day to a few tens of microseconds over more than 30 days free-running after calibration intervals as short as 1 or 2 weeks. The importance of providing an excellent operational environment for such "flywheel" oscillators must be stressed. This means, among other things, the avoidance of physical frequency adjustments, i.e., the control must be exercised with an external phase stepper or in the form of corrections which the local control processor has to apply arithmetically to all measurements.

Table 1. DEVICES EVALUATED

			EVALUATION INTERVAL (Modified Julian Day Numbers)
I.	QUARTZ CRYSTALS		
	1. OSCILLOQUARTZ 51	1 pps	44353 - 44490
	2. OSCILLOQUARTZ 52	1 pps	44352 - 44496
	3. URQ 10	1 pps	44236 - 44359
	4. DISCIPLINED TIME FREQUENCY OSC.	1 pps	43900 - 44280
	5. AUSTRON 1220-9714	5 MHz	44160 - 44420
II.	RUBIDIUMS		
	1. EFRATOM FRT	1 pps	43903 - 44114
	2. HEWLETT-PACKARD 236	5 MHz	44050 - 44350
	3. HEWLETT-PACKARD 229	5 MHz	44120 - 44350
III.	CESIUMS		
	A. HEWLETT-PACKARD (HP)		
	1. HP/5060 207	5 MHz	44120 - 44330
	2. HP/5061 1114	5 MHz	44236 - 44420
	3. HP/5061/2[1] 875	5 MHz	44236 - 44391
	4. HP/5061 549	5 MHz	44120 - 44330
	5. HP/5061/2[1] 1264	5 MHz	44120 - 44350
	B. FREQUENCY TIME SYSTEM (FTS)		
	1. FTS/4050 107	5 MHz	44297 - 44429
	2. FTS/4050 108	5 MHz	44305 - 44429
	C. OSCILLOQUARTZ CO. (OSQ) OSQ 68	5 MHz	44120 - 44350
IV.	HYDROGEN MASER 10[2]	5 MHz	43970 - 44028
V.	QUARTZMATIC #1[3]	1 pps	43730 - 44040

[1]High performance option.

[2]Due to lack of data, calibration intervals greater than 28 days were not computed.

[3]As this device is for comparison purposes only, the first order solution was not computed.

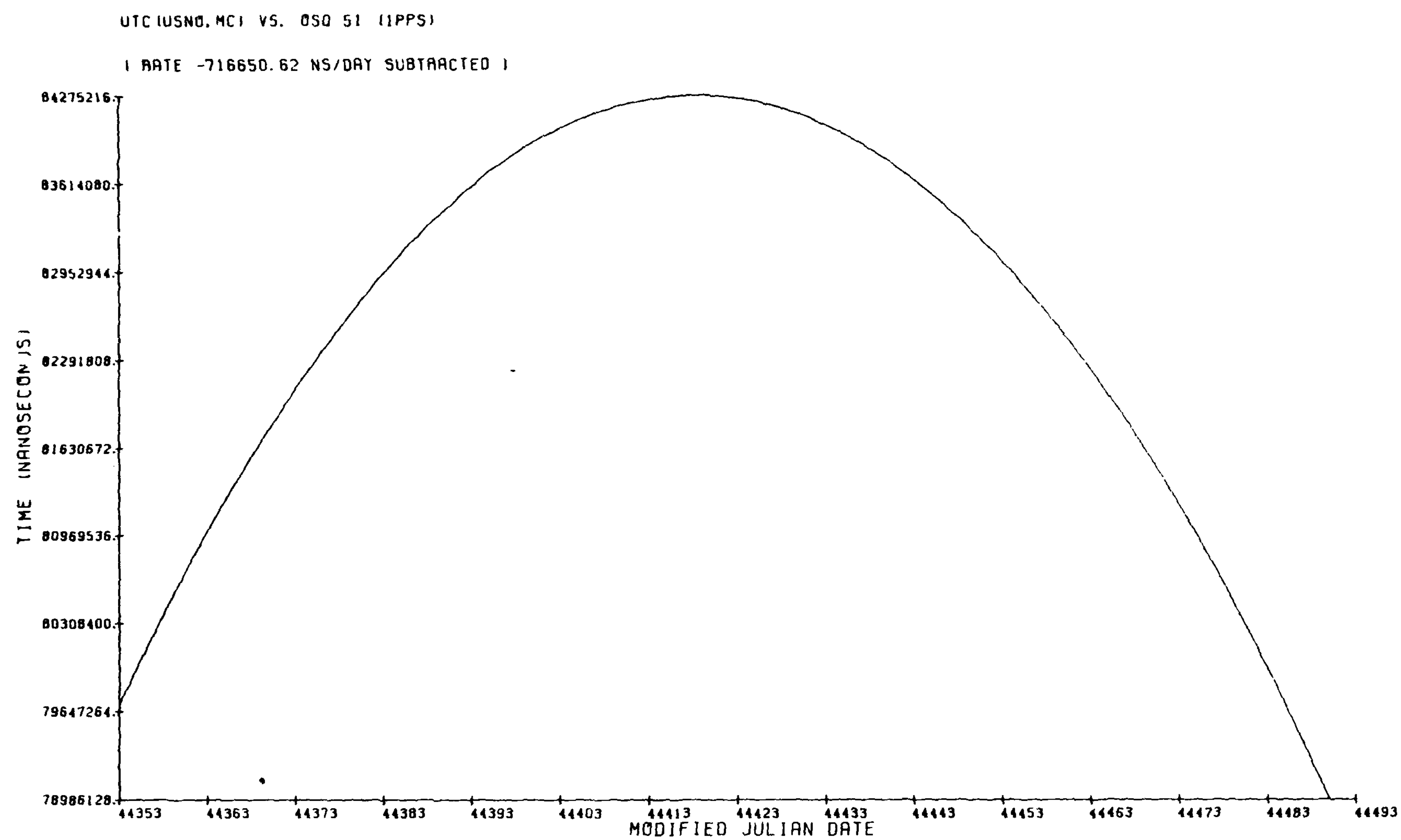


Figure 1. UTC (USNO, MC) Minus UTC (Oscilloquartz Crystal Frequency Oscillator 51)

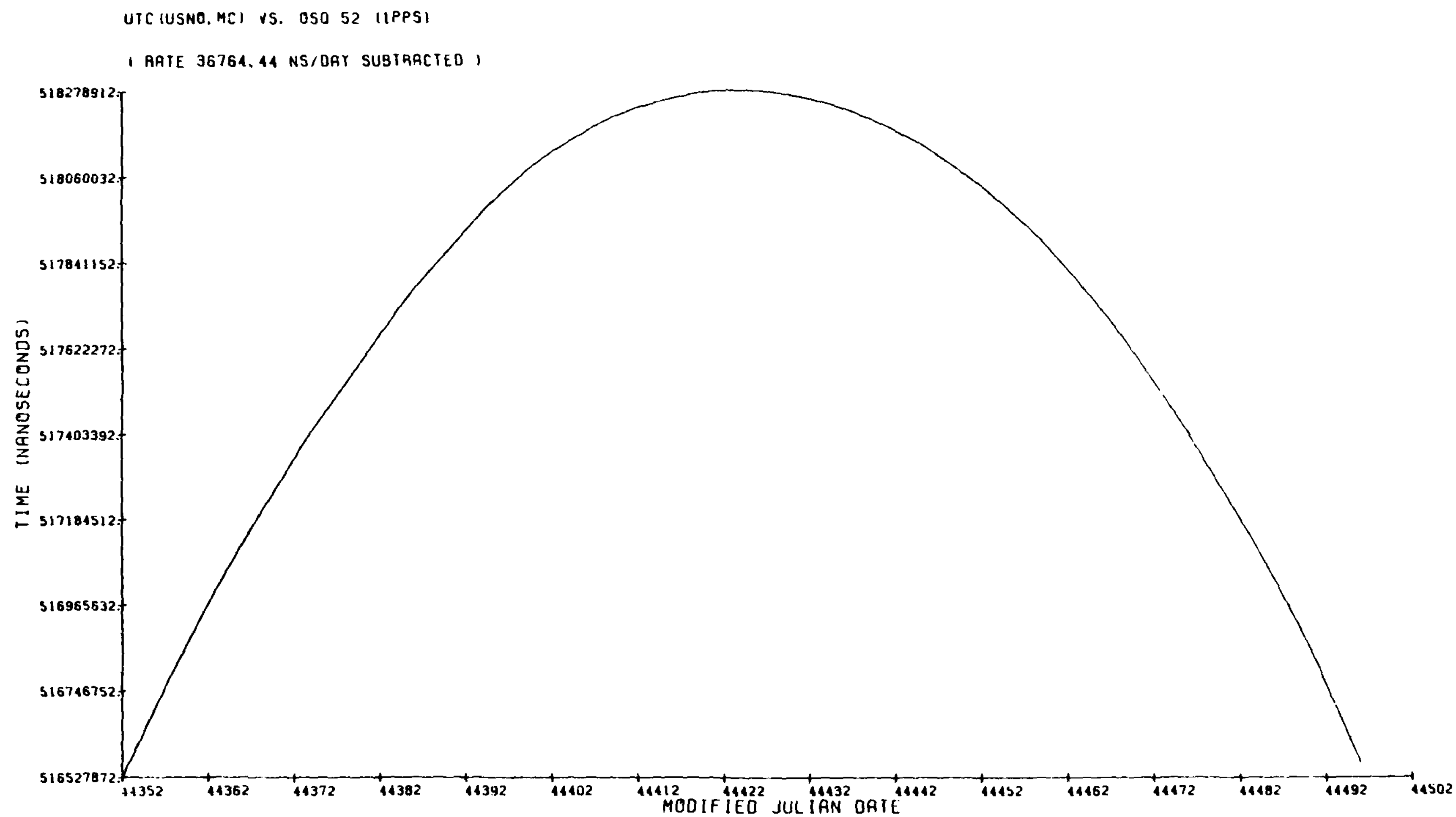


Figure 2. UTC (USNO, MC) Minus UTC (Oscilloquartz Crystal Frequency Oscillator 52)

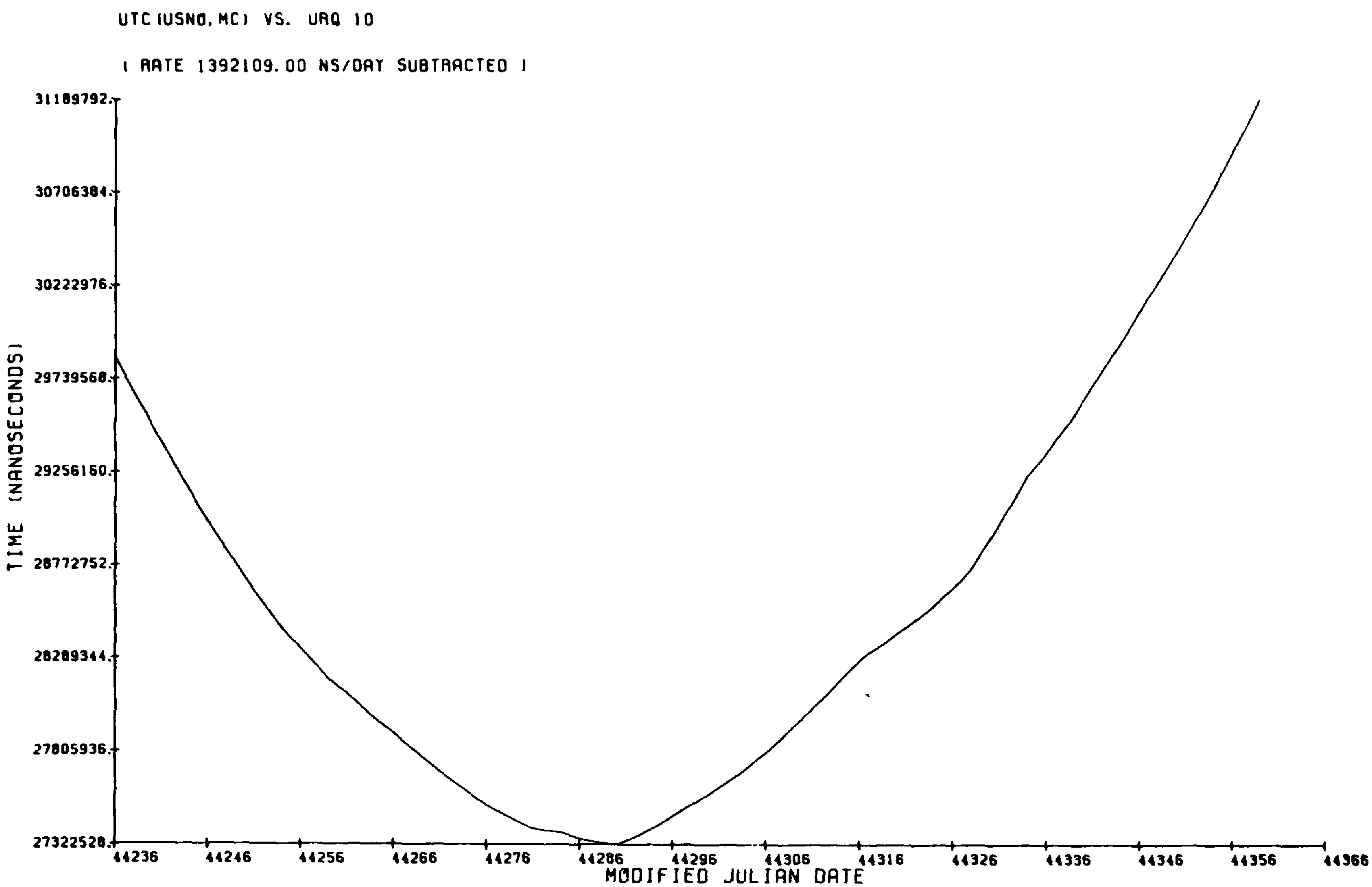


Figure 3. UTC (USNO, MC) Minus UTC (URQ Crystal Frequency Oscillator 10)

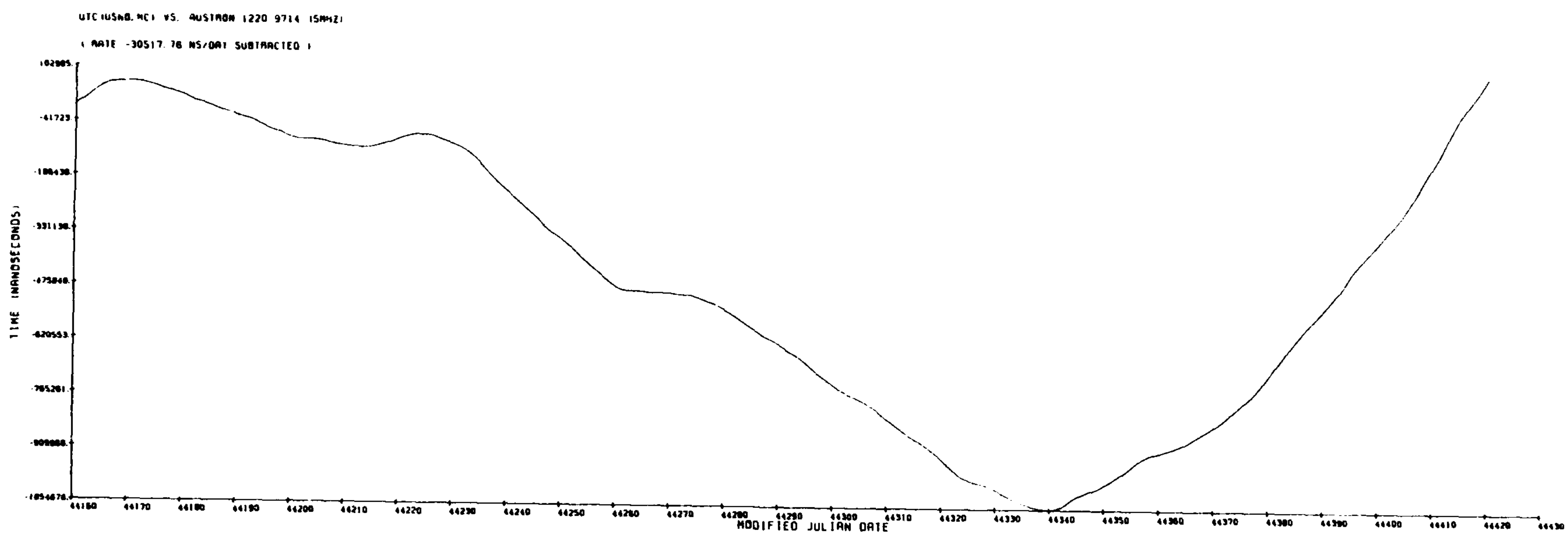


Figure 4. UTC (USNO, MC) Minus UTC (Austron Crystal Frequency Oscillator 9714)

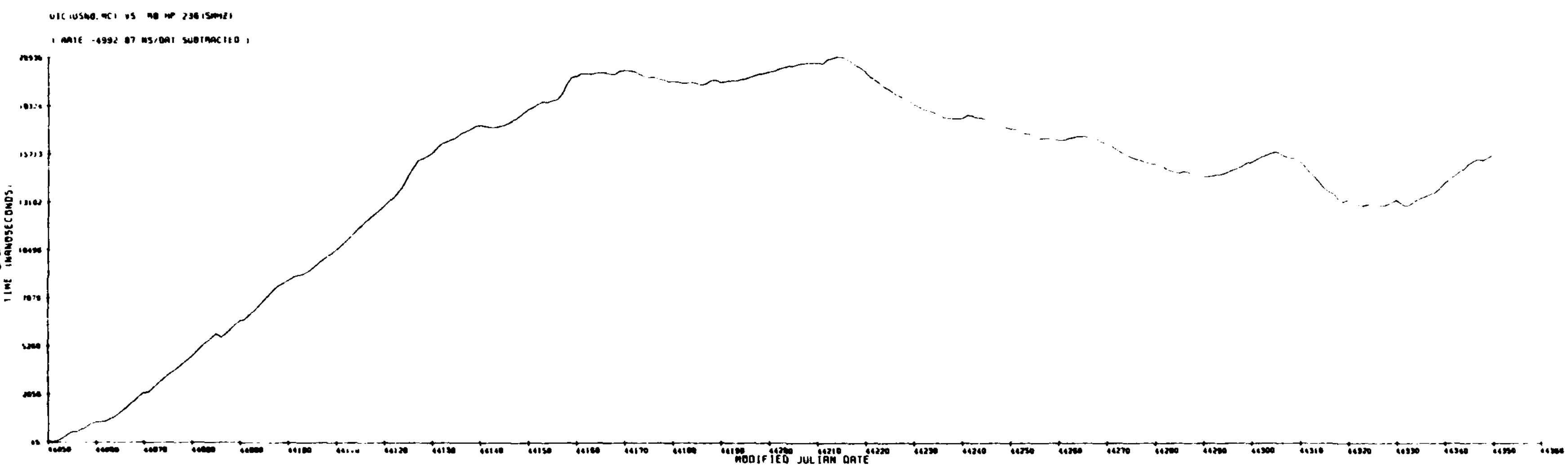


Figure 5. UTC (USNO, MC) Minus UTC (Hewlett-Packard Rubidium Frequency Oscillator 236)

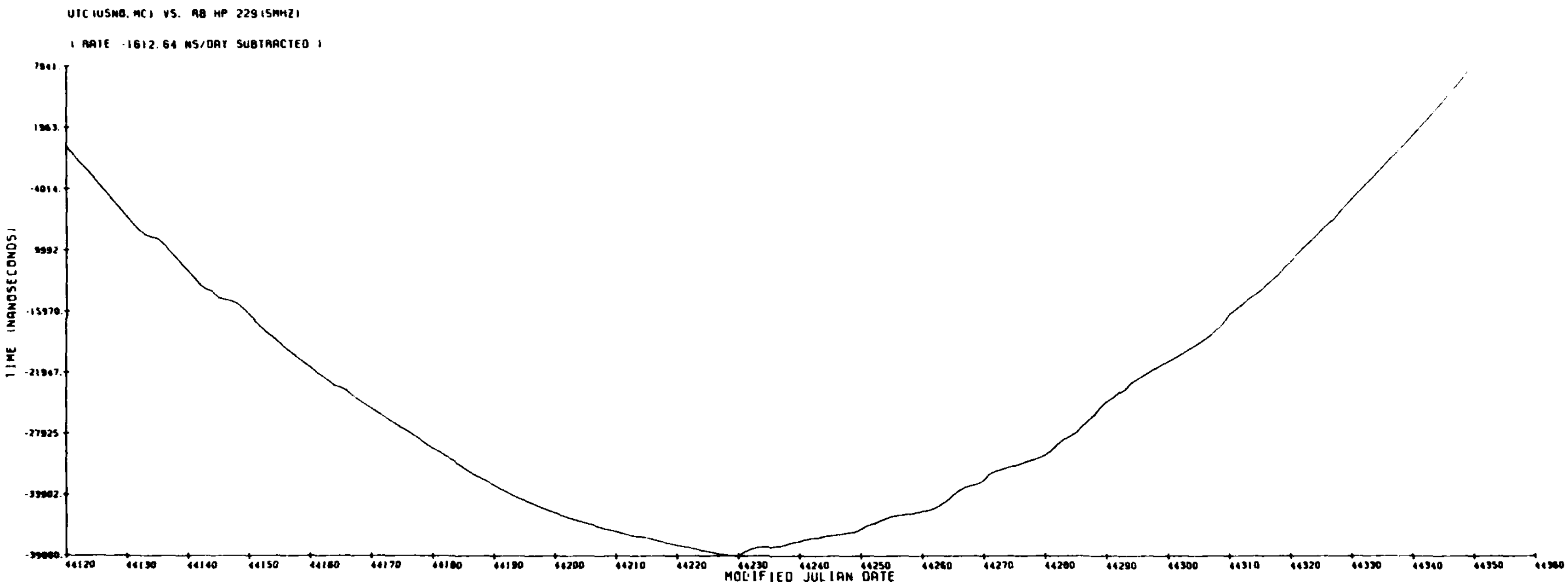


Figure 6. UTC (USNO, MC) Minus UTC (Hewlett-Packard Rubidium Frequency Oscillator 229)

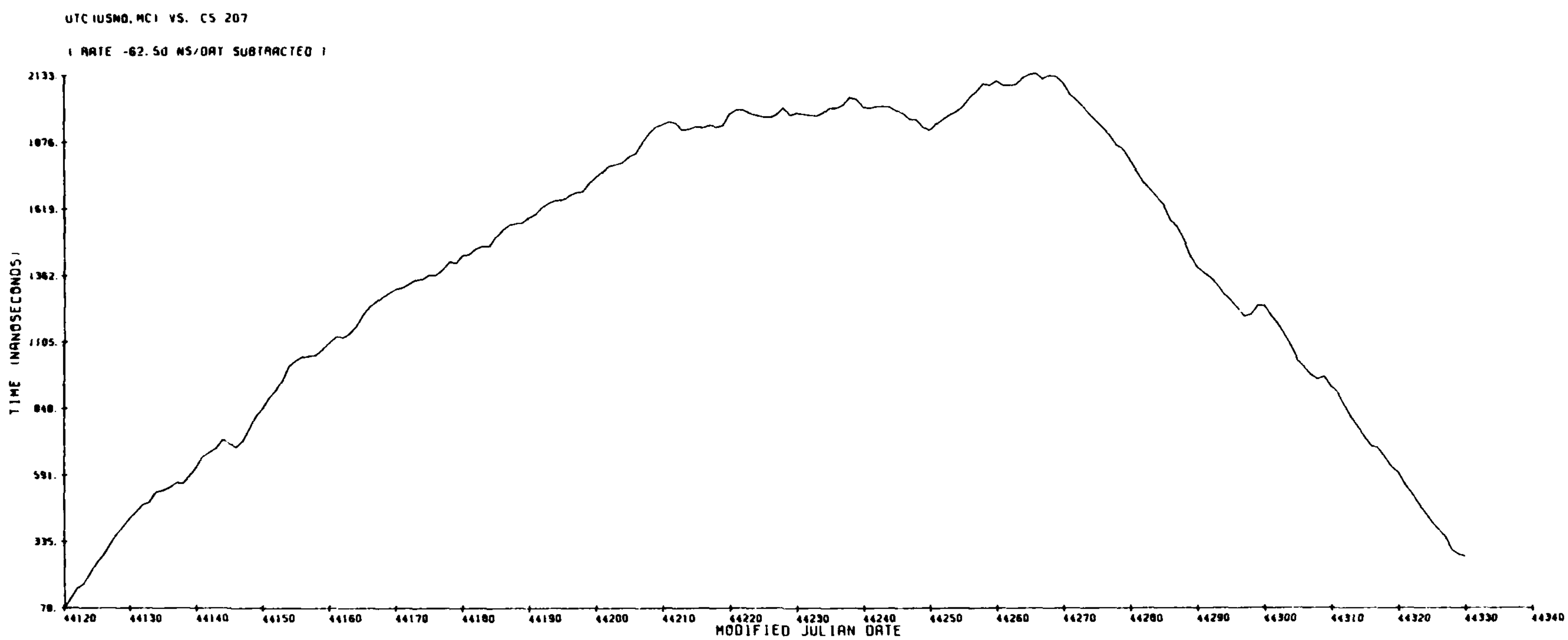


Figure 7. UTC (USNO, MC) Minus UTC (Hewlett-Packard Cesium Frequency Oscillator 207)

Figure 8. UTC (USNO, MC) Minus UTC (Hewlett-Packard Cesium Frequency Oscillator 1114)

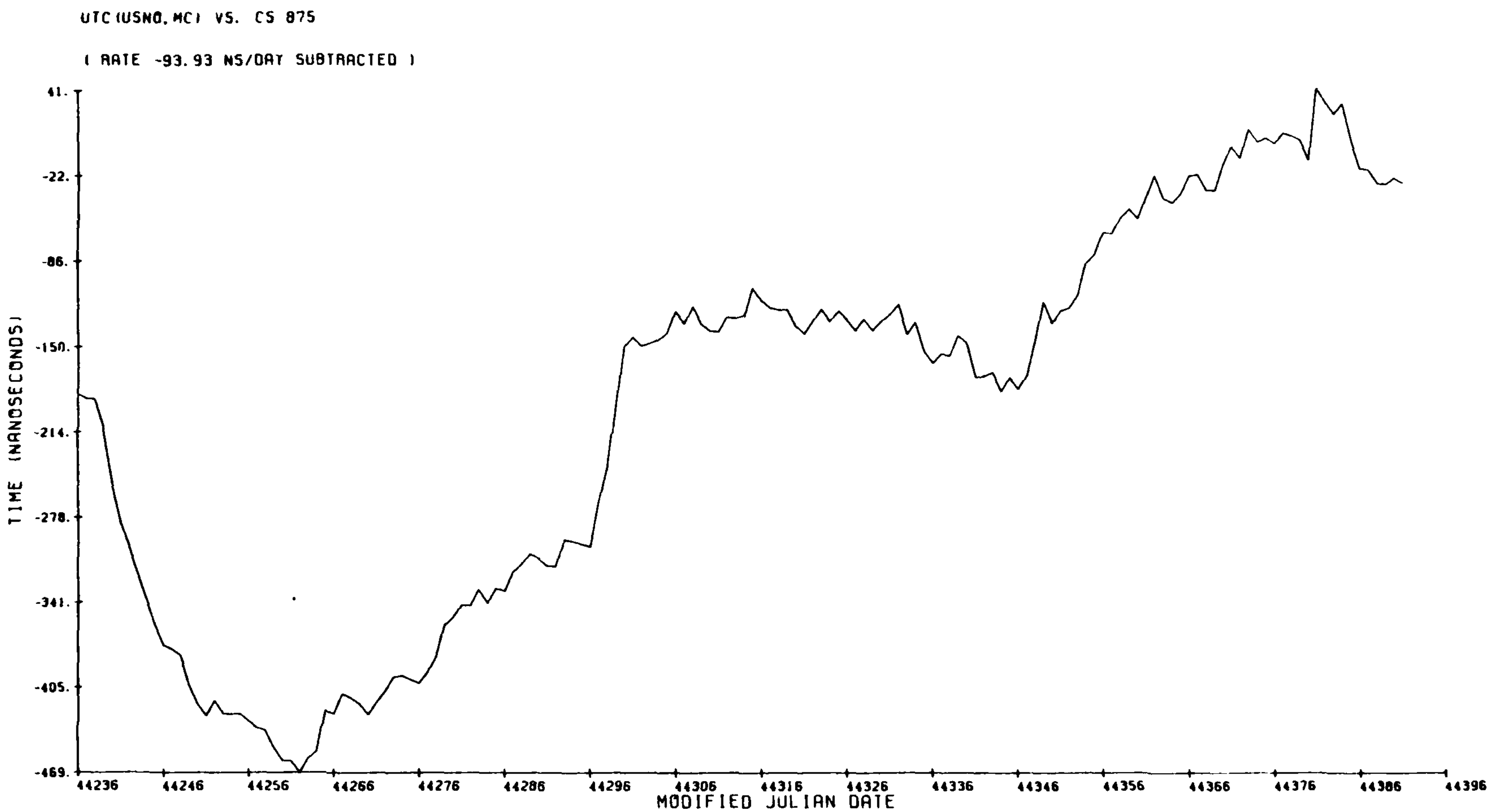


Figure 9. UTC (USNO, MC) Minus UTC (Hewlett-Packard Cesium Frequency Oscillator 875)

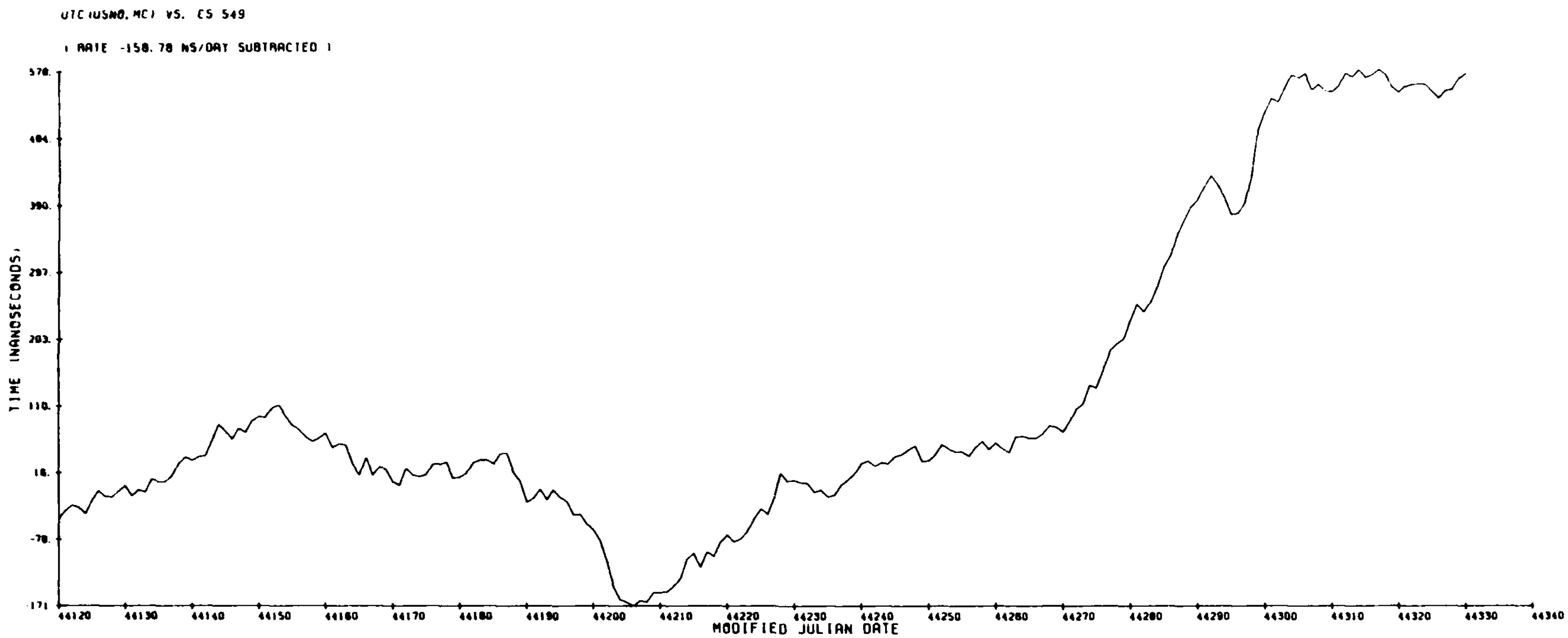


Figure 10. UTC (USNO, MC) (Hewlett-Packard Cesium Frequency Oscillator 549)

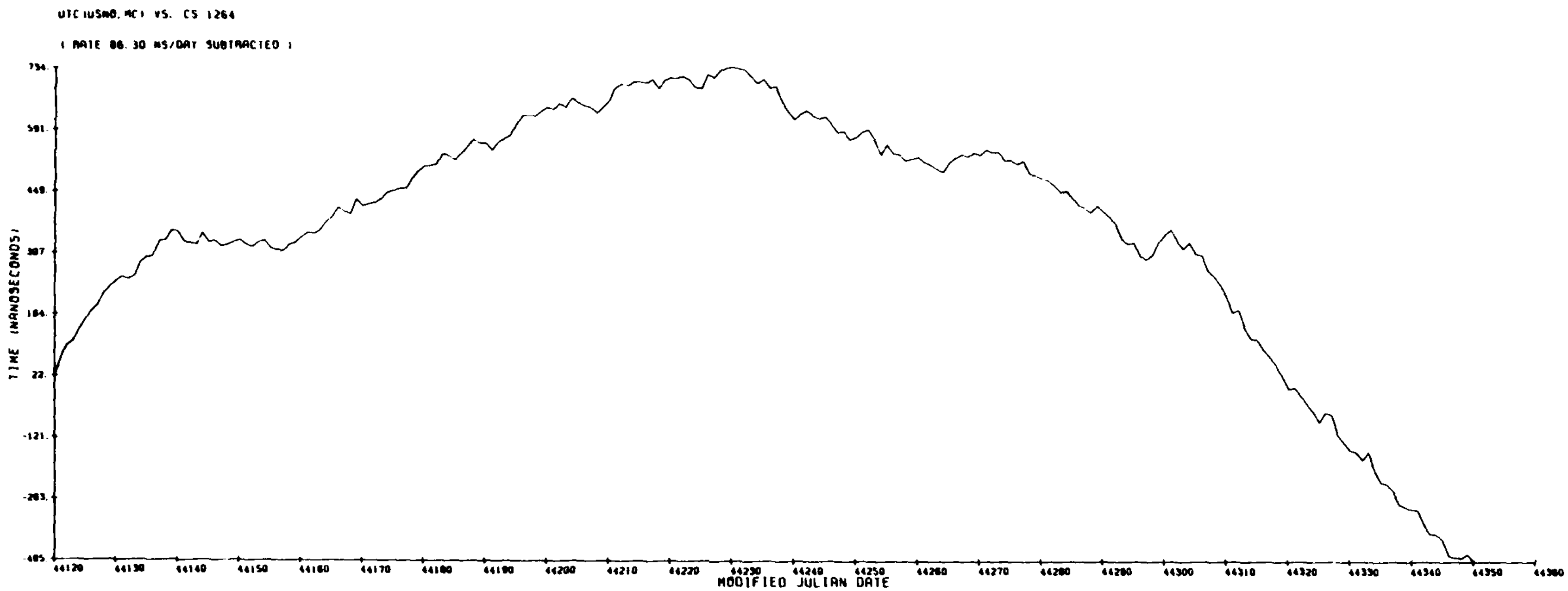


Figure 11. UTC (USNO, MC) Minus UTC (Hewlett-Packard Cesium Frequency Oscillator 1264)

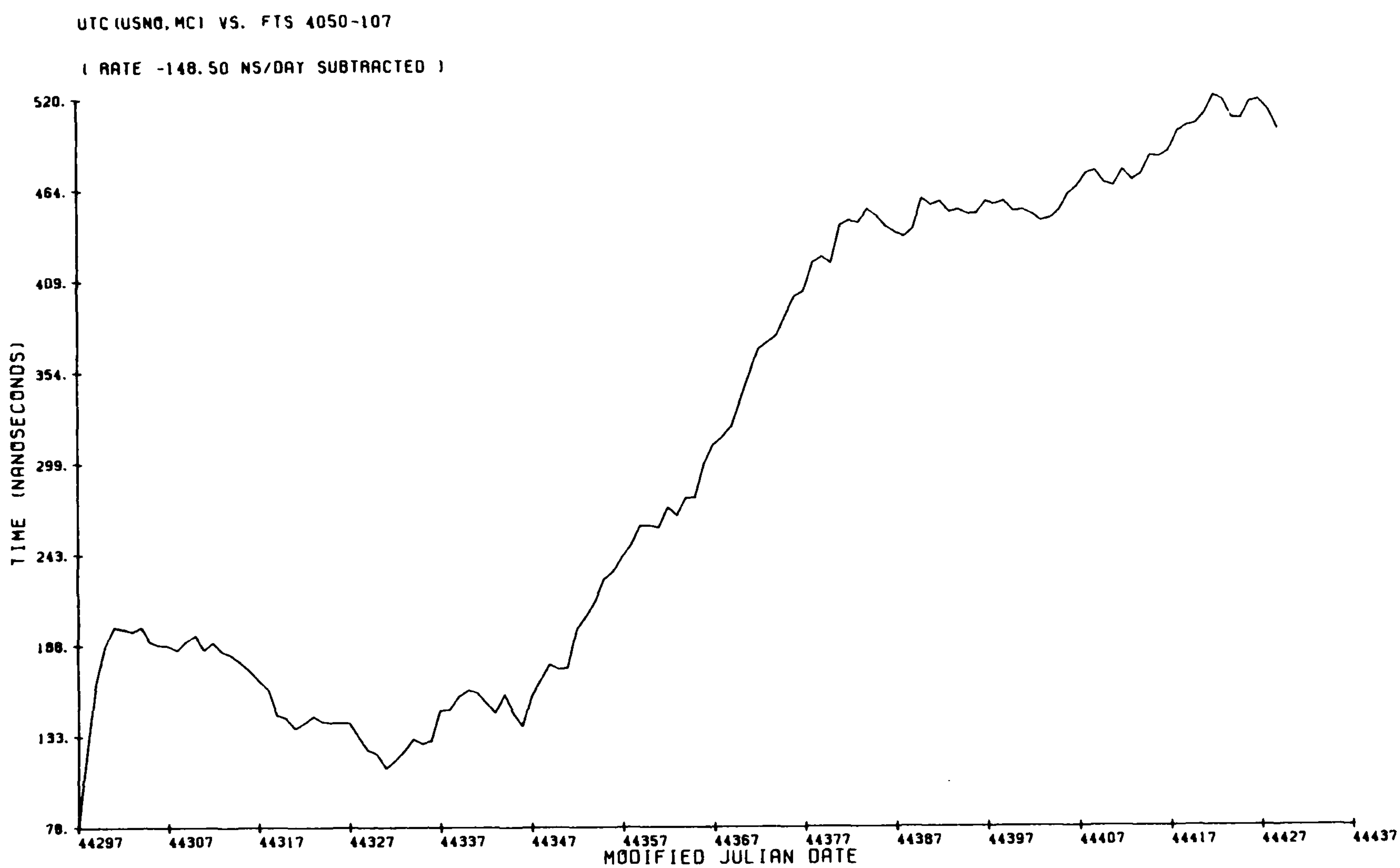


Figure 12. UTC (USNO, MC) Minus UTC (Frequency Time System Frequency Oscillator 107)

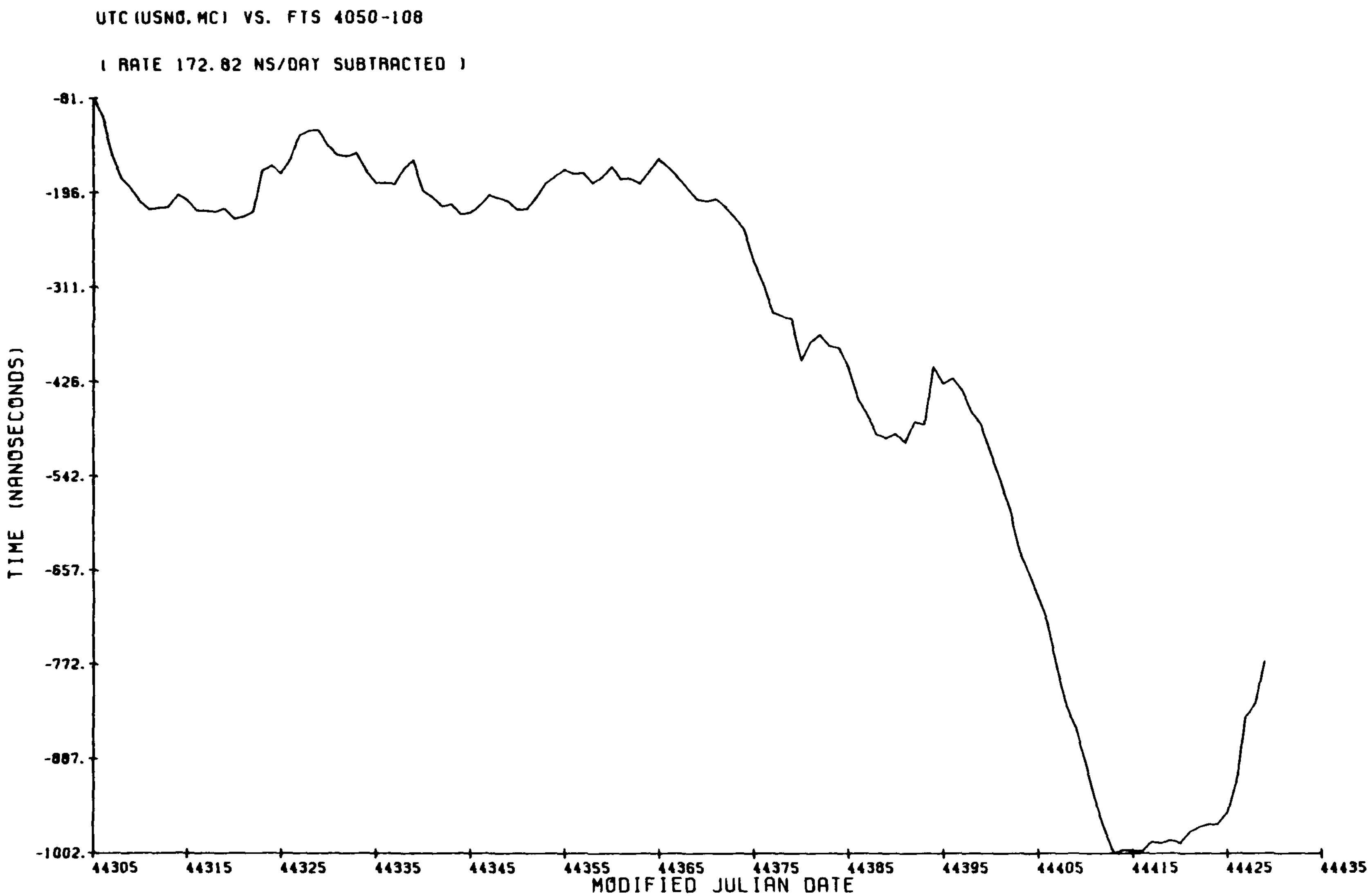


Figure 13. UTC (USNO, MC) Minus UTC (Frequency Time System Frequency Oscillator 108)

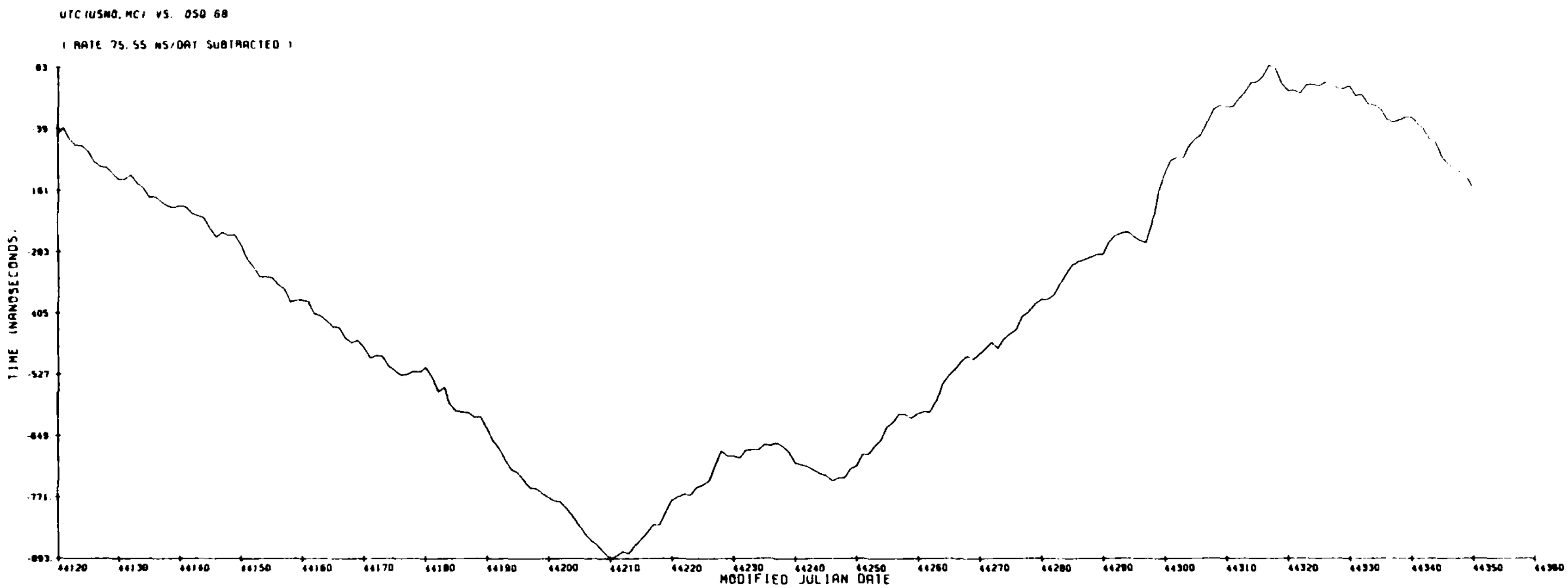


Figure 14. UTC (USNO, MC) Minus UTC (Oscilloquartz Cesium Frequency Oscillator 68)

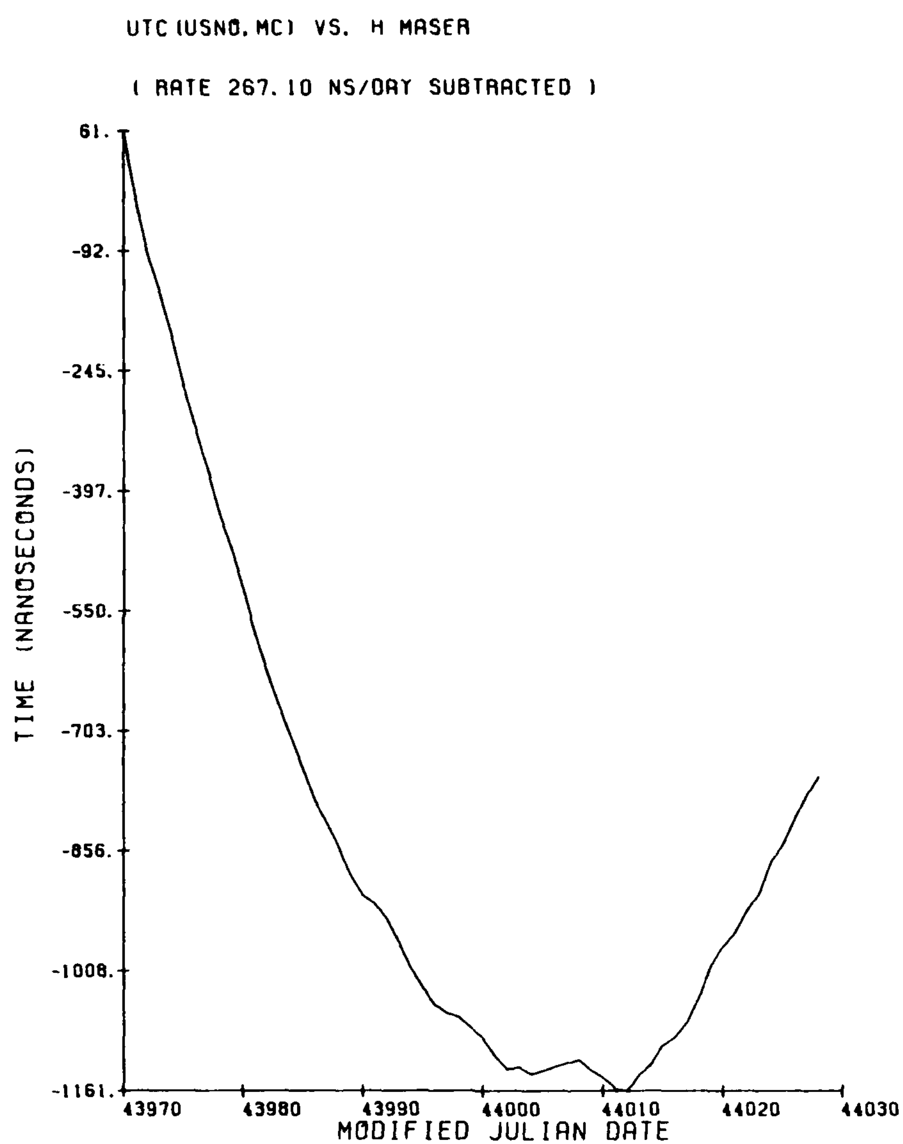


Figure 15. UTC (USNO, MC) Minus UTC (Hydrogen Maser 10)

TABLE 2

RMS PREDICTION ERRORS
FOR
OSCILLOQUARTZ CRYSTAL FREQUENCY OSCILLATOR #51
(1 pps)
MODIFIED JULIAN DAY: 44353 - 44470

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	1.5	12.3	2.2	2.3	3.4	1.4	42.0	1.9	3.0	2.3
2 DAYS	3.5	22.4	4.6	6.2	12.4	2.2	59.0	3.3	5.7	5.4
5 DAYS	10.6	63.7	13.5	32.6	116.6	5.3	121.3	6.6	17.5	25.4
10 DAYS	27.7	173.2	35.0	151.3	917.6	12.4	268.8	13.0	56.0	157.7
15 DAYS	54.5	335.5	69.2	419.7	3570.8	23.5	467.1	24.3	130.2	511.5
20 DAYS	91.2	551.0	115.1	897.7	9712.0	36.8	718.1	39.3	253.5	1264.6
25 DAYS	135.3	819.1	172.7	1648.9	21734.0	54.2	1022.1	58.2	432.4	2534.7
30 DAYS	200.5	1140.1	255.4	2333.4	44454.5	74.4	1377.5	80.5	676.0	4336.5

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	1.1	86.7	2.0	2.4	2.4	1.1	152.6	2.5	2.6	2.5
2 DAYS	2.1	110.6	2.7	3.3	5.2	2.2	183.9	3.3	3.9	4.3
5 DAYS	5.4	195.2	5.3	3.0	19.8	5.4	291.8	5.0	6.4	12.8
10 DAYS	11.2	379.1	9.5	20.9	79.7	16.0	514.7	13.8	15.3	43.5
15 DAYS	20.8	613.9	17.6	45.8	223.0	26.3	789.1	23.3	32.0	104.3
20 DAYS	33.9	903.5	23.2	87.4	499.4	39.6	1116.7	34.5	55.7	210.3
25 DAYS	50.0	1247.2	40.3	153.3	1019.7	52.5	1495.0	46.0	91.9	380.9
30 DAYS	69.0	1644.1	57.1	241.2	1825.7	71.4	1929.4	60.4	142.4	653.1

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	1.2	331.9	4.9	2.6	1.7	0.6	571.7	4.8	2.0	2.9
2 DAYS	1.3	378.5	6.0	3.5	2.6	1.3	631.5	6.1	2.6	3.4
5 DAYS	2.8	530.0	7.4	5.3	6.0	3.3	823.3	9.6	4.2	7.1
10 DAYS	7.0	824.3	13.7	16.8	19.0	6.7	1184.9	14.9	5.1	21.2
15 DAYS	13.5	1167.3	13.0	31.1	45.4	13.2	1598.2	21.7	11.6	42.3
20 DAYS	21.2	1567.6	24.7	50.1	38.3	20.5	2054.3	29.3	20.4	76.4
25 DAYS	30.5	2019.7	32.9	78.6	161.4	29.6	2534.7	41.8	21.7	132.0
30 DAYS	42.7	2520.2	41.4	112.3	260.7	46.6	3156.9	64.6	16.4	236.1

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	76	36	24	15	12	8
2	75	36	24	15	12	8
5	76	36	24	15	12	8
10	75	34	24	15	12	7
15	72	33	22	15	12	7
20	69	31	21	15	12	7
25	67	30	18	15	11	6
30	60	30	17	14	11	4

TABLE 3

RMS PREDICTION ERRORS
FOR
OSCILLOQUARTZ CRYSTAL FREQUENCY OSCILLATOR 552
(1 pps)
MODIFIED JULIAN DAY: 44352 - 44436

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS: ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS: ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.7	4.1	1.5	1.7	1.8	0.8	13.2	2.0	2.3	2.9
2 DAYS	2.0	7.3	2.3	4.3	6.6	1.2	18.6	3.1	4.7	5.7
5 DAYS	7.7	20.6	9.2	23.2	64.5	5.9	38.6	8.1	17.8	32.9
10 DAYS	22.0	55.3	26.4	106.3	521.3	13.5	85.9	17.8	59.7	157.7
15 DAYS	41.2	105.7	45.0	289.7	2043.3	27.7	152.3	34.8	138.0	512.1
20 DAYS	71.5	174.2	83.5	524.3	5593.7	40.3	234.2	55.4	273.9	1252.3
25 DAYS	106.3	259.2	125.4	1135.3	12493.8	60.7	333.1	81.7	466.8	2566.5
30 DAYS	153.5	360.3	181.0	1893.2	24424.2	83.9	450.2	111.0	731.8	4573.1

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS: ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS: ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.9	23.7	2.2	2.0	2.8	0.8	48.3	3.0	2.5	2.2
2 DAYS	1.9	36.9	2.9	3.3	6.0	1.5	58.1	4.1	3.6	3.3
5 DAYS	5.5	64.2	6.7	8.7	23.0	5.2	72.3	7.7	9.3	11.7
10 DAYS	13.3	121.6	13.2	21.0	88.7	11.6	152.4	15.8	22.8	40.1
15 DAYS	20.1	195.6	24.9	46.9	234.9	16.6	248.1	27.6	39.5	88.0
20 DAYS	34.7	283.2	40.6	89.1	509.1	24.1	350.7	41.0	70.0	184.9
25 DAYS	52.1	397.4	59.3	150.2	966.4	36.7	469.9	60.0	112.8	343.2
30 DAYS	74.7	523.2	83.3	239.3	1675.4	51.6	609.2	81.4	166.4	570.3

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS: ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS: ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.7	105.6	5.3	2.6	2.7	0.6	181.0	7.0	4.6	1.8
2 DAYS	1.6	123.7	7.1	3.9	4.1	1.1	200.6	8.2	5.7	3.1
5 DAYS	5.7	170.5	11.4	10.7	12.1	4.9	251.6	12.3	10.7	9.0
10 DAYS	9.2	263.5	19.2	21.3	28.1	13.5	379.3	19.9	23.4	27.4
15 DAYS	15.5	375.0	30.0	41.8	59.4	11.0	508.3	25.7	40.9	24.0
20 DAYS	23.4	503.1	41.3	71.5	109.3	14.7	657.6	31.0	76.7	45.4
25 DAYS	31.2	645.7	53.1	111.3	135.1	17.7	826.8	36.9	116.6	72.0
30 DAYS	39.9	805.9	65.6	163.2	286.5	25.3	1013.0	46.4	164.4	103.9

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL: 7	14	21	28	42	56
DAY 1	80	40	24	20	12	8
2	80	40	24	20	12	8
5	80	40	24	20	12	8
10	77	39	23	19	11	8
15	75	39	23	18	11	7
20	69	36	23	18	11	7
25	67	35	23	17	11	7
30	64	35	22	17	11	7

TABLE 4

RMS PREDICTION ERRORS
FOR
[illegible] CRYSTAL FREQUENCY OSCILLATOR 010
MODIFIED JULIAN DAY: 44236 - 44359

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	6	13	9	9	13	8	47	24	13	19
2 DAYS	16	23	19	23	47	16	66	35	25	49
5 DAYS	58	64	64	128	415	48	137	70	132	255
10 DAYS	173	155	139	640	3219	129	260	148	531	1222
15 DAYS	362	295	383	1741	12461	248	418	265	1282	3540
20 DAYS	544	473	627	3704	33532	412	527	409	2529	7079
25 DAYS	639	698	832	6130	66427	647	702	559	3525	11033
30 DAYS	1133	765	1148	10028	125747	903	1167	768	5545	19442

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	6	72	22	19	19	9	109	45	28	23
2 DAYS	17	91	36	35	38	21	134	63	43	45
5 DAYS	64	164	94	108	149	72	210	115	99	163
10 DAYS	166	308	215	322	615	179	374	218	246	676
15 DAYS	236	478	356	646	1737	295	589	338	430	1689
20 DAYS	425	738	518	970	3726	409	834	461	734	3419
25 DAYS	532	991	700	1543	7152	555	1099	602	1161	6191
30 DAYS	735	1265	920	2297	12465	757	1414	725	1575	6724

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	1	219	41	40	39	11	465	112	72	35
2 DAYS	3	248	46	56	59	23	514	127	91	59
5 DAYS	35	350	62	136	149	72	669	169	175	171
10 DAYS	101	544	122	326	422	151	936	254	359	445
15 DAYS	190	733	246	625	656	231	1233	372	593	873
20 DAYS	380	1204	511	1005	1183	294	1579	481	959	1532
25 DAYS	445	1561	629	1422	2081	378	1921	610	1196	2474
30 DAYS	547	1899	797	1966	3371	419	2338	805	1622	3779

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
2	63	32	20	15	3	8
2	68	32	20	15	3	8
5	68	32	20	16	3	8
10	67	32	19	15	3	8
15	61	32	17	14	5	8
20	61	31	16	14	3	8
25	59	28	16	14	3	8
30	56	23	16	12	3	7

TABLE 5

RMS PREDICTION ERRORS
FOR
DISCIPLINED TIME FREQUENCY OSCILLATOR
MODEL NO. FE150A SERIAL NO. 7522-5129
MODIFIED JULIAN DAY: 43900 - 44230

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	2.2	4.5	3.2	3.4	5.0	2.2	10.6	5.3	4.2	4.9
2 DAYS	5.7	7.7	7.0	9.5	18.2	4.4	14.6	8.3	8.3	12.3
5 DAYS	19.7	13.2	22.2	49.4	154.2	12.8	27.6	19.1	28.5	60.4
10 DAYS	59.0	40.2	65.0	227.4	1271.8	36.9	56.1	46.2	104.7	345.3
15 DAYS	119.0	67.9	130.6	620.7	4804.9	73.3	91.9	88.8	258.1	1065.1
20 DAYS	199.2	79.5	215.3	1307.7	12930.2	124.3	132.2	146.0	514.9	2567.1
25 DAYS	293.7	135.8	326.9	2385.2	28631.4	183.4	178.9	212.2	890.0	5225.7
30 DAYS	420.5	163.3	461.1	3939.3	55304.3	249.7	229.6	287.4	1406.6	9532.4

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	2.4	13.7	7.4	5.5	5.3	2.3	34.7	10.9	7.7	7.6
2 DAYS	5.0	23.4	10.9	9.2	10.8	4.8	41.0	14.4	12.4	14.1
5 DAYS	15.9	39.2	24.2	25.0	42.5	14.6	61.8	28.6	31.1	46.1
10 DAYS	42.4	67.6	55.8	74.5	175.2	39.5	97.8	60.0	90.4	162.6
15 DAYS	79.1	109.4	97.4	162.6	474.1	71.8	135.9	98.5	188.5	403.9
20 DAYS	126.1	150.2	153.1	307.0	1056.5	108.5	131.6	142.9	326.0	329.3
25 DAYS	173.3	200.3	213.3	505.3	2035.2	151.6	237.8	196.5	513.8	1512.7
30 DAYS	238.1	255.9	285.7	778.2	3566.1	201.4	298.3	258.3	758.7	2529.4

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	2.5	49.3	11.8	13.5	10.8	2.2	74.0	25.2	20.9	14.6
2 DAYS	5.1	56.0	14.4	18.5	17.2	4.6	31.3	29.9	27.6	20.2
5 DAYS	13.1	76.2	23.4	36.5	44.6	10.8	104.0	45.4	47.8	37.6
10 DAYS	33.1	110.5	41.3	75.4	133.3	27.4	146.4	74.3	88.5	97.6
15 DAYS	53.3	152.6	66.3	131.4	291.5	43.0	197.4	105.8	145.4	176.3
20 DAYS	92.0	203.7	97.2	210.2	556.7	55.9	253.5	143.0	224.4	322.3
25 DAYS	127.1	259.1	130.6	306.2	946.3	37.9	315.9	182.6	326.7	519.1
30 DAYS	163.0	323.5	170.0	438.5	1523.7	114.1	335.5	226.4	451.2	792.4

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	215	108	72	52	36	24
2	215	108	72	52	36	24
5	215	108	72	52	36	24
10	215	107	72	52	36	24
15	211	104	72	52	36	23
20	210	102	69	52	35	22
25	207	102	68	51	35	22
30	202	102	66	51	34	22

TABLE 6

RMS PREDICTION ERRORS
FOR
AUSTRON CRYSTAL FREQUENCY OSCILLATOR MODEL 1220 #9714
MODIFIED JULIAN DAY: 44150 - 44420

	CALIBRATION INTERVAL 7 DAYS					CALIBRATION INTERVAL 14 DAYS				
PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	2	6	3	3	4	3	10	7	9	4
2 DAYS	6	9	7	9	16	6	14	11	3	11
5 DAYS	22	21	25	51	140	19	23	27	32	60
10 DAYS	60	43	75	247	1053	47	53	60	115	316
15 DAYS	137	70	151	677	3974	89	84	108	271	955
20 DAYS	233	101	256	1447	10663	142	114	163	530	2236
25 DAYS	350	136	332	2587	23293	209	147	245	905	4223
30 DAYS	499	175	547	4291	45301	293	187	339	1411	7615

	CALIBRATION INTERVAL 21 DAYS					CALIBRATION INTERVAL 28 DAYS				
PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	3	18	9	7	7	3	33	12	10	8
2 DAYS	7	23	14	13	15	6	40	17	15	16
5 DAYS	20	38	29	33	61	20	62	34	40	53
10 DAYS	53	69	56	88	250	47	98	74	109	180
15 DAYS	97	101	117	136	669	92	139	129	215	442
20 DAYS	161	141	185	342	1475	142	177	191	365	923
25 DAYS	242	194	276	569	2795	203	217	267	574	1699
30 DAYS	338	228	306	854	4375	272	267	354	837	2880

	CALIBRATION INTERVAL 42 DAYS					CALIBRATION INTERVAL 56 DAYS				
PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	2	49	24	11	9	3	87	40	29	17
2 DAYS	5	56	29	15	15	5	95	47	38	24
5 DAYS	19	79	50	33	43	15	117	69	71	58
10 DAYS	54	120	91	87	132	41	159	119	145	141
15 DAYS	97	165	130	169	291	76	202	176	255	238
20 DAYS	145	213	136	232	548	118	245	236	400	529
25 DAYS	179	254	240	433	925	171	294	320	603	906
30 DAYS	259	327	300	624	1440	223	348	392	820	1415

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION	CALIBRATION INTERVAL					
LEAD TIME	7	14	21	23	42	56
DAY 1	143	72	48	35	24	15
2	143	72	48	36	24	16
5	143	72	48	36	24	15
10	146	72	48	36	23	16
15	144	72	48	35	23	15
20	141	71	47	35	22	15
25	136	68	46	35	21	13
30	129	66	45	35	21	13

TABLE 7

RMS PREDICTION ERRORS
FOR
EFRATOM RUBIDIUM FREQUENCY OSCILLATOR
TYPE FRT
MODIFIED JULIAN DAY: 43903 - 44114

CALIBRATION INTERVAL 7 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.4	1.2	0.6	0.7	1.0
2 DAYS	1.2	1.3	1.5	1.9	3.8
5 DAYS	5.1	3.9	6.0	10.1	35.2
10 DAYS	15.4	7.3	13.9	45.5	232.1
15 DAYS	34.6	10.9	39.6	125.0	1088.4
20 DAYS	57.4	14.4	65.3	261.2	2960.2
25 DAYS	87.7	17.5	100.6	477.9	6648.0
30 DAYS	123.9	21.4	142.4	797.7	13181.9

CALIBRATION INTERVAL 14 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.6	2.6	1.9	1.2	1.2
2 DAYS	1.4	3.3	2.8	2.4	3.6
5 DAYS	4.7	5.1	6.2	10.7	22.2
10 DAYS	12.5	8.9	15.0	39.1	115.9
15 DAYS	23.2	12.7	27.4	92.3	363.7
20 DAYS	37.6	16.1	43.8	182.6	890.0
25 DAYS	54.4	19.8	62.4	318.1	1343.0
30 DAYS	74.1	24.1	85.5	504.2	3389.1

CALIBRATION INTERVAL 21 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.7	3.3	2.7	1.4	1.3
2 DAYS	1.6	4.2	4.2	2.4	2.9
5 DAYS	3.9	6.3	8.2	6.3	13.4
10 DAYS	10.0	10.0	17.5	19.6	60.5
15 DAYS	17.6	14.3	29.4	42.9	157.6
20 DAYS	27.9	16.5	44.4	83.0	388.4
25 DAYS	39.0	19.9	60.7	137.5	743.5
30 DAYS	52.4	23.9	81.4	213.3	1309.3

CALIBRATION INTERVAL 28 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.5	3.6	2.8	3.2	2.6
2 DAYS	1.2	4.3	3.4	4.7	4.6
5 DAYS	3.5	6.5	5.7	10.6	13.9
10 DAYS	8.0	10.2	11.1	28.4	47.1
15 DAYS	13.1	13.6	16.4	57.7	116.6
20 DAYS	20.8	17.4	23.2	102.0	242.6
25 DAYS	29.3	21.6	31.2	162.1	446.6
30 DAYS	39.7	39.7	42.4	250.1	778.9

CALIBRATION INTERVAL 42 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.5	5.0	2.5	3.1	2.3
2 DAYS	1.0	5.6	3.2	4.1	3.8
5 DAYS	2.9	7.3	5.5	7.5	10.6
10 DAYS	5.6	10.8	10.1	16.1	32.2
15 DAYS	11.7	14.7	15.7	28.3	72.5
20 DAYS	15.7	19.6	21.7	43.9	135.0
25 DAYS	17.4	24.9	28.2	64.2	229.6
30 DAYS	24.1	30.7	34.1	89.3	358.0

CALIBRATION INTERVAL 56 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.6	6.5	3.8	3.1	3.7
2 DAYS	1.1	7.0	4.8	4.0	5.2
5 DAYS	1.7	9.1	8.1	7.2	9.9
10 DAYS	3.8	14.2	14.4	12.7	21.1
15 DAYS	6.6	20.4	20.6	18.2	40.7
20 DAYS	9.6	25.9	27.2	24.2	74.2
25 DAYS	10.8	31.4	32.3	30.8	124.4
30 DAYS	14.8	34.4	41.5	42.3	214.1

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	120	60	40	28	20	12
2	120	60	40	28	20	12
5	120	60	40	23	20	12
10	119	60	39	23	20	12
15	114	58	39	[illegible]	19	12
20	113	55	35	27	19	11
25	110	53	35	26	17	11
30	105	52	34	24	19	9

TABLE 8

RMS PREDICTION ERRORS
FOR
HP RUBIDIUM FREQUENCY OSCILLATOR #236
MODIFIED JULIAN DAY: 44050 - 44350

CALIBRATION INTERVAL 7 DAYS / CALIBRATION INTERVAL 14 DAYS

PREDICTION LEAD TIME	ARIMA (7 DAYS)	1ST DEGREE (7 DAYS)	2ND DEGREE (7 DAYS)	3RD DEGREE (7 DAYS)	4TH DEGREE (7 DAYS)	ARIMA (14 DAYS)	1ST DEGREE (14 DAYS)	2ND DEGREE (14 DAYS)	3RD DEGREE (14 DAYS)	4TH DEGREE (14 DAYS)
1 DAY	0.1	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.2	0.1
2 DAYS	0.2	0.2	0.2	0.4	0.8	0.2	0.3	0.3	0.3	0.3
5 DAYS	0.6	0.5	0.7	1.9	7.6	0.5	0.6	0.7	1.0	1.3
10 DAYS	1.9	1.1	2.1	3.7	58.5	1.3	1.1	1.6	3.3	10.0
15 DAYS	3.7	1.7	4.1	23.5	221.5	2.7	1.6	3.1	7.7	31.4
20 DAYS	6.2	2.3	6.8	43.4	598.4	4.4	2.0	4.9	14.9	74.9
25 DAYS	9.4	2.9	10.3	83.2	1323.5	6.4	2.4	7.0	25.4	154.5
30 DAYS	13.3	3.4	14.5	142.4	2513.7	8.6	2.7	9.4	40.0	283.4

CALIBRATION INTERVAL 21 DAYS / CALIBRATION INTERVAL 28 DAYS

PREDICTION LEAD TIME	ARIMA (21 DAYS)	1ST DEGREE (21 DAYS)	2ND DEGREE (21 DAYS)	3RD DEGREE (21 DAYS)	4TH DEGREE (21 DAYS)	ARIMA (28 DAYS)	1ST DEGREE (28 DAYS)	2ND DEGREE (28 DAYS)	3RD DEGREE (28 DAYS)	4TH DEGREE (28 DAYS)
1 DAY	0.1	0.3	0.2	0.2	0.2	0.1	0.5	0.3	0.2	0.2
2 DAYS	0.2	0.4	0.3	0.3	0.4	0.2	0.6	0.5	0.4	0.4
5 DAYS	0.4	0.7	0.6	0.8	1.4	0.5	1.0	0.9	0.9	1.0
10 DAYS	1.1	1.2	1.3	2.3	5.6	1.1	1.6	1.7	2.4	3.5
15 DAYS	2.2	1.7	2.4	5.0	15.1	1.9	1.9	2.7	5.1	9.0
20 DAYS	3.4	2.1	3.6	9.2	33.2	2.8	2.2	3.8	9.1	18.5
25 DAYS	4.6	2.5	4.9	15.0	63.4	3.8	2.3	5.0	13.5	33.3
30 DAYS	5.2	2.8	6.2	23.0	110.4	4.8	2.6	6.2	20.0	56.6

CALIBRATION INTERVAL 42 DAYS / CALIBRATION INTERVAL 56 DAYS

PREDICTION LEAD TIME	ARIMA (42 DAYS)	1ST DEGREE (42 DAYS)	2ND DEGREE (42 DAYS)	3RD DEGREE (42 DAYS)	4TH DEGREE (42 DAYS)	ARIMA (56 DAYS)	1ST DEGREE (56 DAYS)	2ND DEGREE (56 DAYS)	3RD DEGREE (56 DAYS)	4TH DEGREE (56 DAYS)
1 DAY	0.1	0.7	0.5	0.4	0.4	0.1	0.8	0.9	0.6	0.4
2 DAYS	0.2	0.7	0.6	0.6	0.6	0.2	0.9	1.1	0.8	0.6
5 DAYS	0.5	0.9	1.1	1.3	1.4	0.5	1.2	1.6	1.4	1.5
10 DAYS	1.1	1.3	2.1	2.8	4.2	1.1	1.5	2.3	2.4	4.0
15 DAYS	1.9	1.7	3.2	5.1	9.1	1.8	1.8	3.0	3.8	7.6
20 DAYS	2.2	2.0	4.1	7.9	16.8	2.6	2.2	3.6	5.5	13.7
25 DAYS	3.0	2.4	4.3	11.6	24.8	3.4	2.5	4.1	7.6	22.5
30 DAYS	3.2	3.0	5.3	14.1	39.5	4.5	2.9	4.8	10.2	34.7

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	172	84	56	40	28	20
2	172	84	56	40	28	20
5	172	84	56	40	28	20
10	172	83	56	40	28	19
15	172	79	55	38	28	18
20	171	78	54	38	27	18
25	169	77	54	37	25	18
30	167	77	54	37	25	18

TABLE 9

RMS PREDICTION ERRORS
FOR
HP RUBIDIUM FREQUENCY OSCILLATOR #229
MODIFIED JULIAN DAY: 44120 - 44350

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.1	0.2	0.2	0.2	0.3	0.1	0.3	0.2	0.2	0.2
2 DAYS	0.3	0.3	0.4	0.5	1.1	0.2	0.4	0.4	0.4	0.5
5 DAYS	0.9	0.7	1.1	2.6	9.7	0.6	0.7	0.8	1.5	2.6
10 DAYS	2.7	1.2	3.1	12.0	73.9	1.4	1.1	1.8	5.1	13.7
15 DAYS	5.3	1.7	6.1	32.8	279.2	2.4	1.8	3.2	12.0	43.3
20 DAYS	8.7	2.5	10.1	69.3	751.7	3.7	2.5	4.9	23.0	105.1
25 DAYS	13.1	3.3	15.1	126.8	1603.7	5.5	3.4	7.2	39.6	220.3
30 DAYS	13.5	4.4	21.2	205.8	3247.1	7.5	4.6	9.8	62.5	406.1

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.1	0.4	0.4	0.3	0.3	0.1	0.6	0.4	0.3	0.3
2 DAYS	0.3	0.5	0.5	0.4	0.7	0.2	0.7	0.5	0.5	0.6
5 DAYS	0.7	0.8	0.9	1.2	2.9	0.6	1.0	0.8	1.2	2.1
10 DAYS	1.5	1.4	1.6	3.7	11.5	1.3	1.7	1.5	3.2	7.4
15 DAYS	2.5	2.1	2.5	8.1	31.1	2.0	2.5	2.1	6.2	17.9
20 DAYS	3.9	2.9	3.6	15.0	58.2	2.6	3.5	2.9	10.4	36.4
25 DAYS	5.5	3.9	4.9	24.9	130.7	3.6	4.6	3.9	16.4	65.5
30 DAYS	7.2	5.0	6.5	38.5	225.7	4.8	5.8	4.9	24.1	110.8

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.1	0.9	0.3	0.4	0.3	0.1	1.6	0.4	0.4	0.5
2 DAYS	0.2	1.1	0.4	0.6	0.4	0.2	1.8	0.5	0.5	0.6
5 DAYS	0.4	1.4	0.6	0.9	0.8	0.4	2.4	0.7	0.8	1.4
10 DAYS	0.7	2.3	0.9	1.7	2.0	0.7	3.6	0.9	1.1	2.9
15 DAYS	1.1	3.3	1.2	3.2	4.3	1.3	4.8	1.0	1.8	5.3
20 DAYS	1.6	4.4	1.6	4.8	8.2	1.7	6.2	1.2	2.5	9.0
25 DAYS	2.3	5.7	2.2	7.0	14.1	2.1	7.7	1.5	3.4	14.3
30 DAYS	3.1	7.2	2.6	10.0	22.7	2.7	9.3	1.9	4.6	19.2

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	132	64	44	32	20	15
2	132	64	44	32	20	16
5	132	64	44	32	20	15
10	132	63	44	31	20	16
15	130	61	43	31	20	16
20	127	59	42	30	20	16
25	126	55	41	29	20	15
30	122	52	40	29	20	15

TABLE 10

RMS PREDICTION ERRORS
FOR
HP CESIUM FREQUENCY OSCILLATOR #207
MODIFIED JULIAN DAY: 44120 - 44330

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
	CALIBRATION INTERVAL 7 DAYS					CALIBRATION INTERVAL 14 DAYS				
1 DAY	0.02	0.03	0.03	0.03	0.05	0.02	0.04	0.03	0.03	0.04
2 DAYS	0.04	0.04	0.05	0.08	0.17	0.03	0.05	0.05	0.05	0.10
5 DAYS	0.15	0.07	0.17	0.40	1.49	0.09	0.07	0.10	0.18	0.55
10 DAYS	0.41	0.14	0.46	1.78	11.55	0.23	0.14	0.24	0.63	2.26
15 DAYS	0.79	0.20	0.88	4.79	43.62	0.40	0.20	0.44	1.49	8.58
20 DAYS	1.30	0.27	1.44	10.04	118.03	0.62	0.28	0.69	2.38	19.92
25 DAYS	1.95	0.34	2.13	18.13	260.05	0.87	0.36	0.94	4.70	33.86
30 DAYS	2.69	0.40	2.87	28.22	483.22	1.19	0.42	1.29	6.95	59.63
	CALIBRATION INTERVAL 21 DAYS					CALIBRATION INTERVAL 28 DAYS				
1 DAY	0.02	0.05	0.05	0.04	0.04	0.02	0.06	0.04	0.04	0.05
2 DAYS	0.04	0.07	0.07	0.06	0.08	0.03	0.07	0.06	0.06	0.08
5 DAYS	0.08	0.10	0.12	0.16	0.29	0.06	0.08	0.10	0.14	0.23
10 DAYS	0.15	0.16	0.24	0.42	1.19	0.12	0.14	0.20	0.36	0.75
15 DAYS	0.23	0.22	0.41	0.87	3.22	0.22	0.19	0.33	0.71	1.85
20 DAYS	0.44	0.28	0.62	1.59	6.64	0.36	0.25	0.51	1.21	3.77
25 DAYS	0.66	0.35	0.88	2.61	11.64	0.49	0.34	0.69	1.39	6.44
30 DAYS	0.91	0.43	1.10	3.97	17.31	0.67	0.42	0.88	2.51	10.49
	CALIBRATION INTERVAL 42 DAYS					CALIBRATION INTERVAL 56 DAYS				
1 DAY	0.01	0.06	0.05	0.04	0.04	0.02	0.14	0.08	0.07	0.03
2 DAYS	0.02	0.07	0.06	0.05	0.05	0.02	0.15	0.08	0.08	0.06
5 DAYS	0.07	0.10	0.10	0.10	0.14	0.05	0.19	0.12	0.15	0.12
10 DAYS	0.15	0.16	0.13	0.24	0.42	0.12	0.23	0.19	0.33	0.31
15 DAYS	0.25	0.24	0.27	0.42	0.90	0.16	0.32	0.27	0.53	0.62
20 DAYS	0.41	0.31	0.39	0.68	1.59	0.24	0.41	0.37	0.79	1.02
25 DAYS	0.57	0.38	0.51	0.94	2.92	0.28	0.48	0.38	0.99	1.73
30 DAYS	0.71	0.47	0.62	1.30	4.57	0.31	0.56	0.45	1.36	2.74

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
1	120	60	40	28	20	12
2	120	60	40	28	20	12
5	120	60	40	28	20	12
10	117	58	40	28	20	12
15	117	56	39	28	20	12
20	115	55	37	27	20	11
25	113	52	35	26	19	10
30	111	51	33	24	19	10

TABLE 11

RMS PREDICTION ERRORS
FOR
HP CESIUM FREQUENCY OSCILLATOR #1114
MODIFIED JULIAN DAY: 44236 - 44420

PREDICTION LEAD TIME	ARIMA (7 DAYS)	1ST DEGREE (7 DAYS)	2ND DEGREE (7 DAYS)	3RD DEGREE (7 DAYS)	4TH DEGREE (7 DAYS)	ARIMA (14 DAYS)	1ST DEGREE (14 DAYS)	2ND DEGREE (14 DAYS)	3RD DEGREE (14 DAYS)	4TH DEGREE (14 DAYS)
1 DAY	0.01	0.02	0.02	0.02	0.03	0.01	0.02	0.02	0.02	0.02
2 DAYS	0.03	0.03	0.03	0.05	0.12	0.02	0.03	0.03	0.03	0.04
5 DAYS	0.09	0.05	0.09	0.27	1.00	0.05	0.04	0.05	0.11	0.17
10 DAYS	0.26	0.09	0.25	1.25	7.81	0.11	0.06	0.12	0.41	0.87
15 DAYS	0.50	0.11	0.47	3.38	29.61	0.19	0.08	0.20	0.94	2.76
20 DAYS	0.84	0.15	0.79	7.15	80.07	0.30	0.10	0.31	1.79	6.42
25 DAYS	1.27	0.13	1.18	13.03	177.59	0.45	0.12	0.46	3.12	12.86
30 DAYS	1.73	0.22	1.65	21.52	342.54	0.61	0.14	0.64	4.84	23.70

PREDICTION LEAD TIME	ARIMA (21 DAYS)	1ST DEGREE (21 DAYS)	2ND DEGREE (21 DAYS)	3RD DEGREE (21 DAYS)	4TH DEGREE (21 DAYS)	ARIMA (28 DAYS)	1ST DEGREE (28 DAYS)	2ND DEGREE (28 DAYS)	3RD DEGREE (28 DAYS)	4TH DEGREE (28 DAYS)
1 DAY	0.01	0.02	0.03	0.03	0.02	0.01	0.03	0.02	0.03	0.03
2 DAYS	0.02	0.03	0.04	0.05	0.05	0.01	0.03	0.02	0.04	0.06
5 DAYS	0.04	0.04	0.07	0.12	0.18	0.04	0.04	0.04	0.10	0.18
10 DAYS	0.09	0.05	0.13	0.31	0.78	0.10	0.05	0.08	0.22	0.60
15 DAYS	0.15	0.03	0.21	0.65	2.19	0.16	0.07	0.11	0.42	1.47
20 DAYS	0.22	0.10	0.30	1.17	4.92	0.22	0.10	0.15	0.70	2.98
25 DAYS	0.31	0.12	0.42	1.97	10.07	0.31	0.14	0.21	1.08	5.40
30 DAYS	0.42	0.15	0.55	3.01	17.73	0.39	0.16	0.27	1.57	9.00

PREDICTION LEAD TIME	ARIMA (42 DAYS)	1ST DEGREE (42 DAYS)	2ND DEGREE (42 DAYS)	3RD DEGREE (42 DAYS)	4TH DEGREE (42 DAYS)	ARIMA (56 DAYS)	1ST DEGREE (56 DAYS)	2ND DEGREE (56 DAYS)	3RD DEGREE (56 DAYS)	4TH DEGREE (56 DAYS)
1 DAY	0.01	0.03	0.01	0.03	0.03	0.01	0.05	0.03	0.02	0.03
2 DAYS	0.02	0.03	0.02	0.04	0.04	0.01	0.06	0.03	0.03	0.04
5 DAYS	0.06	0.04	0.04	0.09	0.10	0.03	0.07	0.04	0.04	0.06
10 DAYS	0.10	0.07	0.06	0.16	0.21	0.07	0.09	0.06	0.08	0.13
15 DAYS	0.16	0.06	0.11	0.26	0.34	0.10	0.11	0.08	0.13	0.24
20 DAYS	0.22	0.09	0.14	0.38	0.59	0.14	0.13	0.12	0.19	0.41
25 DAYS	0.29	0.11	0.17	0.54	0.95	0.18	0.17	0.17	0.26	0.63
30 DAYS	0.40	0.14	0.23	0.70	1.51	0.25	0.21	0.23	0.34	0.83

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	104	52	32	24	16	12
2	104	52	32	24	16	12
5	104	52	32	24	16	12
10	102	52	31	24	15	12
15	102	51	30	23	14	12
20	97	49	29	23	14	11
25	95	45	25	23	14	11
30	93	43	23	23	13	10

TABLE 12

RMS PREDICTION ERRORS
FOR
HP CESIUM FREQUENCY OSCILLATOR #875
MODIFIED JULIAN DAY: 44236 - 44391

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.03
2 DAYS	0.03	0.03	0.03	0.06	0.15	0.03	0.03	0.03	0.04	0.06
5 DAYS	0.09	0.04	0.08	0.32	1.26	0.08	0.04	0.06	0.12	0.30
10 DAYS	0.27	0.03	0.22	1.47	7.30	0.19	0.08	0.13	0.41	1.45
15 DAYS	0.55	0.12	0.44	4.06	34.14	0.28	0.12	0.23	0.92	4.20
20 DAYS	0.85	0.16	0.71	8.53	83.67	0.45	0.15	0.35	1.77	9.94
25 DAYS	1.30	0.21	1.07	15.59	195.10	0.68	0.21	0.51	3.07	20.61
30 DAYS	1.82	0.25	1.52	25.84	379.09	0.93	0.25	0.69	4.37	37.95

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.04	0.03	0.02	0.02	0.01	0.04	0.03	0.02	0.03
2 DAYS	0.03	0.04	0.03	0.04	0.06	0.02	0.05	0.04	0.04	0.05
5 DAYS	0.07	0.05	0.06	0.11	0.22	0.05	0.07	0.06	0.09	0.13
10 DAYS	0.17	0.08	0.13	0.30	0.87	0.08	0.11	0.11	0.20	0.46
15 DAYS	0.29	0.11	0.20	0.60	2.31	0.14	0.14	0.16	0.40	1.11
20 DAYS	0.45	0.14	0.32	1.10	5.16	0.21	0.18	0.22	0.69	2.24
25 DAYS	0.66	0.19	0.45	1.83	10.18	0.30	0.22	0.30	1.08	4.03
30 DAYS	0.92	0.22	0.61	2.75	18.01	0.37	0.27	0.38	1.54	6.84

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.06	0.03	0.02	0.03	0.01	0.06	0.04	0.02	0.03
2 DAYS	0.02	0.07	0.04	0.04	0.05	0.01	0.06	0.05	0.03	0.04
5 DAYS	0.04	0.08	0.06	0.07	0.12	0.03	0.09	0.06	0.07	0.08
10 DAYS	0.09	0.11	0.10	0.15	0.33	0.06	0.11	0.11	0.13	0.20
15 DAYS	0.16	0.14	0.15	0.26	0.70	0.10	0.14	0.17	0.20	0.40
20 DAYS	0.23	0.13	0.21	0.41	1.27	0.16	0.17	0.24	0.34	0.67
25 DAYS	0.34	0.21	0.30	0.59	2.09	0.19	0.20	0.31	0.53	1.04
30 DAYS	0.50	0.22	0.40	0.86	3.28	0.28	0.20	0.37	0.72	1.71

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
1	83	44	28	20	12	8
2	83	44	28	20	12	8
5	83	44	28	20	12	8
10	82	44	28	19	12	8
15	81	42	28	19	12	8
20	79	42	26	19	12	7
25	77	40	24	19	12	6
30	74	39	23	18	12	5

TABLE 13

RMS PREDICTION ERRORS
FOR
HP CESIUM FREQUENCY OSCILLATOR #549
MODIFIED JULIAN DAY: 44120 - 44330

CALIBRATION INTERVAL 7 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.02	0.02	0.02	0.04
2 DAYS	0.04	0.03	0.05	0.06	0.15
5 DAYS	0.12	0.05	0.13	0.32	1.36
10 DAYS	0.37	0.10	0.40	1.49	10.46
15 DAYS	0.71	0.15	0.77	4.06	39.73
20 DAYS	1.19	0.21	1.27	8.57	107.87
25 DAYS	1.73	0.26	1.89	15.61	233.95
30 DAYS	2.43	0.29	2.59	24.75	451.87

CALIBRATION INTERVAL 14 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.03	0.02	0.02	0.03
2 DAYS	0.03	0.03	0.04	0.04	0.05
5 DAYS	0.07	0.05	0.09	0.14	0.29
10 DAYS	0.16	0.08	0.20	0.40	1.49
15 DAYS	0.30	0.12	0.35	1.05	4.63
20 DAYS	0.48	0.16	0.55	1.79	11.04
25 DAYS	0.71	0.19	0.72	3.34	21.21
30 DAYS	0.96	0.21	0.89	4.95	35.25

CALIBRATION INTERVAL 21 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.03	0.03	0.04	0.03
2 DAYS	0.03	0.04	0.04	0.07	0.07
5 DAYS	0.05	0.05	0.07	0.18	0.23
10 DAYS	0.13	0.10	0.12	0.47	0.96
15 DAYS	0.23	0.14	0.19	0.98	2.63
20 DAYS	0.34	0.18	0.28	1.67	4.64
25 DAYS	0.43	0.22	0.39	2.32	9.06
30 DAYS	0.65	0.25	0.49	3.10	15.07

CALIBRATION INTERVAL 28 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.04	0.03	0.03	0.04
2 DAYS	0.03	0.05	0.04	0.04	0.05
5 DAYS	0.06	0.07	0.06	0.09	0.13
10 DAYS	0.12	0.11	0.09	0.19	0.57
15 DAYS	0.20	0.13	0.17	0.33	1.35
20 DAYS	0.29	0.17	0.25	0.62	2.80
25 DAYS	0.42	0.20	0.34	0.98	4.84
30 DAYS	0.52	0.21	0.47	1.38	6.49

CALIBRATION INTERVAL 42 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.05	0.04	0.03	0.03
2 DAYS	0.03	0.04	0.05	0.05	0.04
5 DAYS	0.04	0.05	0.08	0.09	0.10
10 DAYS	0.09	0.09	0.14	0.20	0.25
15 DAYS	0.15	0.12	0.22	0.36	0.51
20 DAYS	0.21	0.16	0.30	0.56	0.96
25 DAYS	0.27	0.19	0.38	0.84	1.61
30 DAYS	0.32	0.20	0.46	1.16	2.42

CALIBRATION INTERVAL 56 DAYS

PREDICTION LEAD TIME	ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.08	0.06	0.04	0.03
2 DAYS	0.03	0.08	0.07	0.05	0.05
5 DAYS	0.06	0.08	0.10	0.12	0.11
10 DAYS	0.10	0.13	0.15	0.22	0.27
15 DAYS	0.16	0.16	0.21	0.38	0.51
20 DAYS	0.25	0.16	0.27	0.51	0.93
25 DAYS	0.35	0.20	0.32	0.90	1.54
30 DAYS	0.43	0.22	0.38	1.24	2.29

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	120	60	40	23	20	12
2	120	60	40	23	20	12
5	120	60	40	23	20	12
10	119	58	40	23	20	12
15	117	56	39	23	20	12
20	115	55	37	27	20	11
25	113	52	35	26	19	10
30	111	51	33	24	19	10

TABLE 14

RMS PREDICTION ERRORS
FOR
HP CESIUM FREQUENCY OSCILLATOR #1264
MODIFIED JULIAN DAY: 44120 - 44350

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.02	0.02	0.03	0.05	0.02	0.02	0.02	0.02	0.03
2 DAYS	0.04	0.02	0.04	0.07	0.16	0.04	0.03	0.03	0.04	0.07
5 DAYS	0.11	0.05	0.11	0.35	1.37	0.09	0.05	0.06	0.12	0.33
10 DAYS	0.31	0.09	0.27	1.63	10.68	0.21	0.07	0.13	0.42	1.58
15 DAYS	0.60	0.13	0.56	4.44	39.23	0.40	0.09	0.23	0.99	4.73
20 DAYS	0.95	0.17	0.90	9.38	105.59	0.65	0.12	0.36	1.94	11.30
25 DAYS	1.42	0.21	1.31	16.72	224.65	0.92	0.15	0.52	3.25	23.37
30 DAYS	2.00	0.25	1.85	27.78	431.36	1.29	0.18	0.73	5.25	43.25

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03
2 DAYS	0.02	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.05
5 DAYS	0.05	0.05	0.07	0.10	0.15	0.05	0.05	0.06	0.09	0.15
10 DAYS	0.13	0.09	0.13	0.30	0.60	0.10	0.08	0.11	0.21	0.52
15 DAYS	0.23	0.12	0.21	0.65	1.61	0.17	0.11	0.17	0.39	1.23
20 DAYS	0.33	0.14	0.32	1.21	3.51	0.23	0.13	0.23	0.69	2.66
25 DAYS	0.51	0.17	0.44	2.02	5.69	0.34	0.16	0.31	1.07	4.93
30 DAYS	0.69	0.21	0.58	3.11	11.69	0.45	0.20	0.39	1.56	8.24

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.03	0.03	0.03	0.03	0.02	0.05	0.03	0.04	0.03
2 DAYS	0.03	0.03	0.04	0.04	0.04	0.02	0.06	0.04	0.05	0.05
5 DAYS	0.05	0.05	0.05	0.07	0.08	0.05	0.08	0.05	0.08	0.11
10 DAYS	0.09	0.08	0.09	0.13	0.19	0.08	0.11	0.09	0.16	0.24
15 DAYS	0.14	0.10	0.14	0.22	0.39	0.12	0.14	0.11	0.26	0.48
20 DAYS	0.20	0.13	0.13	0.35	0.75	0.17	0.16	0.14	0.39	0.80
25 DAYS	0.28	0.15	0.22	0.54	1.29	0.22	0.19	0.19	0.54	1.26
30 DAYS	0.35	0.18	0.29	0.76	2.04	0.26	0.23	0.25	0.69	1.90

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	132	64	44	32	20	16
2	132	64	44	32	20	16
5	132	64	44	32	20	16
10	132	63	44	31	20	16
15	130	61	43	31	20	16
20	129	59	42	30	20	15
25	126	55	41	29	20	15
30	122	52	40	29	20	15

TABLE 15

RMS PREDICTION ERRORS
FOR
FTS CESIUM FREQUENCY OSCILLATOR MODEL 4050 #107
MODIFIED JULIAN DAY: 44297 - 44429

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01
2 DAYS	0.02	0.01	0.02	0.03	0.08	0.01	0.02	0.02	0.02	0.03
5 DAYS	0.05	0.02	0.05	0.17	0.69	0.03	0.03	0.04	0.07	0.14
10 DAYS	0.17	0.05	0.15	0.76	5.19	0.08	0.04	0.07	0.25	0.77
15 DAYS	0.32	0.07	0.23	2.10	19.10	0.15	0.07	0.14	0.57	2.42
20 DAYS	0.50	0.10	0.44	4.47	50.91	0.24	0.10	0.23	1.08	5.60
25 DAYS	0.75	0.15	0.65	8.18	112.69	0.36	0.13	0.33	1.77	11.49
30 DAYS	1.04	0.17	0.91	13.45	219.39	0.50	0.17	0.46	2.79	20.57

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01
2 DAYS	0.01	0.02	0.02	0.02	0.03	0.01	0.03	0.02	0.01	0.02
5 DAYS	0.03	0.02	0.03	0.05	0.10	0.02	0.04	0.04	0.04	0.06
10 DAYS	0.06	0.04	0.05	0.15	0.43	0.06	0.06	0.07	0.11	0.18
15 DAYS	0.11	0.05	0.09	0.32	1.17	0.12	0.09	0.12	0.22	0.45
20 DAYS	0.18	0.07	0.14	0.60	2.60	0.20	0.13	0.17	0.39	0.91
25 DAYS	0.25	0.10	0.20	0.96	4.96	0.29	0.16	0.23	0.63	1.64
30 DAYS	0.33	0.13	0.29	1.51	9.06	0.40	0.20	0.29	0.96	2.76

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.04	0.01	0.01	0.02	0.01	0.06	0.03	0.02	0.02
2 DAYS	0.01	0.04	0.02	0.02	0.03	0.01	0.16	0.04	0.02	0.02
5 DAYS	0.02	0.05	0.03	0.04	0.06	0.02	0.08	0.05	0.04	0.04
10 DAYS	0.05	0.08	0.05	0.08	0.15	0.04	0.10	0.08	0.09	0.11
15 DAYS	0.09	0.12	0.08	0.14	0.33	0.07	0.12	0.12	0.14	0.22
20 DAYS	0.13	0.14	0.12	0.24	0.62	0.11	0.14	0.16	0.23	0.34
25 DAYS	0.20	0.17	0.15	0.37	1.07	0.17	0.15	0.21	0.33	0.46
30 DAYS	0.28	0.20	0.19	0.54	1.69	0.23	0.17	0.26	0.46	0.67

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	76	35	24	16	12	8
2	76	36	24	16	12	8
5	75	36	24	16	12	8
10	74	35	24	16	12	8
15	70	34	22	15	10	8
20	64	30	21	15	10	7
25	62	23	21	15	9	5
30	61	27	19	14	8	5

TABLE 16

RMS PREDICTION ERRORS
FOR
FTS CESIUM FREQUENCY OSCILLATOR MODEL 4050 #108
MODIFIED JULIAN DAY: 44305 - 44429

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.03	0.02	0.03	0.06	0.01	0.04	0.04	0.03	0.03
2 DAYS	0.04	0.04	0.04	0.08	0.20	0.03	0.06	0.05	0.05	0.07
5 DAYS	0.14	0.08	0.14	0.37	1.72	0.08	0.10	0.11	0.21	0.33
10 DAYS	0.42	0.17	0.42	1.75	13.16	0.21	0.19	0.28	0.71	1.89
15 DAYS	0.83	0.28	0.60	4.86	50.69	0.40	0.25	0.56	1.68	5.67
20 DAYS	1.41	0.35	1.33	10.06	136.04	0.59	0.23	0.89	3.44	13.84
25 DAYS	2.14	0.35	1.96	18.23	300.40	0.92	0.23	1.24	5.78	28.34
30 DAYS	2.96	0.38	2.69	30.16	584.95	0.95	0.23	1.12	8.45	52.81

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.05	0.05	0.03	0.04	0.02	0.08	0.09	0.04	0.04
2 DAYS	0.03	0.07	0.07	0.04	0.08	0.03	0.10	0.12	0.07	0.08
5 DAYS	0.09	0.12	0.13	0.14	0.32	0.08	0.16	0.21	0.19	0.25
10 DAYS	0.21	0.22	0.26	0.42	1.23	0.23	0.28	0.43	0.55	0.80
15 DAYS	0.38	0.13	0.32	1.00	3.33	0.37	0.21	0.41	1.09	1.74
20 DAYS	0.60	0.20	0.46	1.91	7.14	0.54	0.20	0.56	1.35	3.33
25 DAYS	0.87	0.19	0.59	3.18	13.44	0.47	0.22	0.61	1.75	5.64
30 DAYS	1.05	0.24	0.74	2.94	18.57	0.53	0.21	0.65	2.54	7.35

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.07	0.07	0.06	0.03	0.03	0.09	0.08	0.09	0.06
2 DAYS	0.03	0.07	0.08	0.08	0.06	0.03	0.10	0.09	0.10	0.07
5 DAYS	0.07	0.08	0.14	0.16	0.18	0.07	0.15	0.12	0.17	0.16
10 DAYS	0.13	0.15	0.29	0.38	0.54	0.16	0.21	0.15	0.32	0.46
15 DAYS	0.28	0.13	0.22	0.57	1.03	0.25	0.28	0.16	0.47	0.91
20 DAYS	0.35	0.20	0.25	0.86	1.90	0.32	0.32	0.14	0.59	1.54
25 DAYS	0.38	0.27	0.23	1.17	3.17	0.39	0.36	0.21	0.72	2.39
30 DAYS	0.41	0.32	0.30	1.54	5.00	0.28	0.44	0.31	0.97	3.63

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	63	32	20	16	8	8
2	63	32	20	16	8	8
5	63	32	20	16	8	8
10	63	32	20	16	8	8
15	64	32	18	12	7	8
20	62	30	18	12	7	8
25	59	29	13	10	7	8
30	57	25	16	9	7	7

TABLE 17

RMS PREDICTION ERRORS
FOR
OSCILLOQUARTZ CESIUM FREQUENCY OSCILLATOR #68
MODIFIED JULIAN DAY: 44120 - 44350

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.02	0.02	0.02	0.04	0.01	0.03	0.02	0.03	0.03
2 DAYS	0.03	0.03	0.04	0.06	0.12	0.03	0.04	0.04	0.05	0.06
5 DAYS	0.10	0.05	0.11	0.33	1.11	0.07	0.06	0.07	0.14	0.31
10 DAYS	0.28	0.09	0.30	1.50	3.71	0.17	0.10	0.15	0.47	1.55
15 DAYS	0.54	0.14	0.58	4.06	33.10	0.31	0.15	0.26	1.08	4.84
20 DAYS	0.89	0.20	0.95	8.54	90.05	0.50	0.20	0.41	2.11	11.63
25 DAYS	1.33	0.25	1.42	15.62	200.91	0.75	0.25	0.59	3.36	23.91
30 DAYS	1.83	0.32	1.93	24.91	382.05	1.05	0.30	0.77	5.11	40.60

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03
2 DAYS	0.02	0.04	0.04	0.03	0.04	0.03	0.04	0.04	0.04	0.05
5 DAYS	0.06	0.06	0.07	0.08	0.15	0.05	0.06	0.07	0.07	0.15
10 DAYS	0.13	0.10	0.13	0.23	0.59	0.12	0.11	0.15	0.17	0.43
15 DAYS	0.23	0.15	0.22	0.48	1.53	0.20	0.16	0.25	0.33	1.15
20 DAYS	0.37	0.22	0.34	0.88	3.31	0.30	0.22	0.34	0.59	2.37
25 DAYS	0.52	0.23	0.49	1.45	5.09	0.41	0.26	0.45	0.96	4.27
30 DAYS	0.70	0.34	0.64	2.17	10.51	0.53	0.30	0.56	1.44	7.13

PREDICTION LEAD TIME	CALIBRATION INTERVAL 42 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 56 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.02	0.04	0.04	0.03	0.03	0.01	0.07	0.05	0.04	0.03
2 DAYS	0.02	0.05	0.05	0.04	0.05	0.02	0.07	0.06	0.05	0.05
5 DAYS	0.04	0.07	0.09	0.07	0.10	0.04	0.09	0.08	0.09	0.11
10 DAYS	0.09	0.03	0.16	0.15	0.27	0.08	0.12	0.14	0.19	0.23
15 DAYS	0.16	0.12	0.26	0.25	0.58	0.13	0.16	0.20	0.33	0.55
20 DAYS	0.23	0.15	0.33	0.36	1.11	0.20	0.20	0.25	0.50	0.98
25 DAYS	0.32	0.20	0.41	0.54	1.91	0.27	0.26	0.31	0.70	1.60
30 DAYS	0.43	0.23	0.52	0.76	3.05	0.38	0.28	0.36	0.97	2.34

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	132	64	44	32	20	16
2	132	64	44	32	20	16
5	132	64	44	32	20	16
10	132	63	44	31	20	16
15	130	61	43	31	20	16
20	129	59	42	30	20	16
25	126	55	41	29	20	16
30	122	52	40	29	20	15

TABLE 18

RMS PREDICTION ERRORS
FOR
HYDROGEN MASER #10
MODIFIED JULIAN DAY: 43970 - 44023

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 14 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.02	0.02	0.02	0.03	0.01	0.03	0.01	0.02	0.02
2 DAYS	0.03	0.05	0.03	0.05	0.11	0.01	0.05	0.02	0.03	0.05
5 DAYS	0.08	0.05	0.09	0.25	0.97	0.05	0.11	0.04	0.07	0.36
10 DAYS	0.23	0.15	0.25	1.17	7.34	0.11	0.21	0.07	0.25	1.84
15 DAYS	0.38	0.29	0.45	3.05	28.70	0.22	0.38	0.10	0.54	5.74
20 DAYS	0.57	0.44	0.64	6.49	79.26	0.28	0.60	0.10	0.64	11.18
25 DAYS	0.81	0.66	0.92	12.24	173.46	0.39	0.84	0.15	1.09	22.57
30 DAYS	1.20	0.93	1.27	18.29	365.65	0.75	1.14	0.17	2.34	41.95

PREDICTION LEAD TIME	CALIBRATION INTERVAL 21 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE	CALIBRATION INTERVAL 28 DAYS ARIMA	1ST DEGREE	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	0.01	0.03	0.02	0.02	0.02	0.01	0.12	0.02	0.02	0.02
2 DAYS	0.02	0.10	0.03	0.04	0.03	0.03	0.15	0.03	0.03	0.04
5 DAYS	0.04	0.17	0.05	0.07	0.13	0.07	0.23	0.05	0.05	0.13
10 DAYS	0.10	0.35	0.07	0.16	0.56	0.12	0.42	0.07	0.11	0.38
15 DAYS	0.19	0.52	0.09	0.35	1.27	0.18	0.64	0.07	0.20	0.95
20 DAYS	0.12	0.74	0.19	0.76	2.52	0.19	0.90	0.06	0.24	1.58
25 DAYS	0.08	1.05	0.26	1.38	5.29	0.17	1.21	0.13	0.63	1.19
30 DAYS	0.10	1.39	0.33	2.03	9.09	----	----	----	----	----

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF MICROSECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28
DAY 1	32	16	8	8
2	32	16	8	8
5	32	16	8	8
10	31	15	8	8
15	27	15	6	5
20	25	13	4	3
25	23	12	3	1
30	13	4	3	----

TABLE 19

RMS PREDICTION ERRORS
FOR
QUARTZMATIC #1
MODIFIED JULIAN DAY: 43730 - 44040

CALIBRATION INTERVAL
7 DAYS

PREDICTION LEAD TIME	ARIMA	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	.013	.020	.024	.038
2 DAYS	.035	.043	.072	.137
5 DAYS	.125	.135	.391	1.231
10 DAYS	.373	.391	1.782	9.564
15 DAYS	.740	.772	4.304	36.326
20 DAYS	1.109	1.145	9.735	98.021
25 DAYS	1.670	1.723	17.645	217.230
30 DAYS	2.373	2.444	29.075	423.963

CALIBRATION INTERVAL
14 DAYS

ARIMA	2ND DEGREE	3RD DEGREE	4TH DEGREE
0.015	0.032	0.036	0.038
0.034	0.055	0.069	0.094
0.095	0.134	0.215	0.493
0.244	0.320	0.709	2.657
0.474	0.596	1.462	7.249
0.731	0.892	2.792	15.830
1.149	1.274	4.740	32.244
1.600	1.769	7.451	59.191

CALIBRATION INTERVAL
21 DAYS

PREDICTION LEAD TIME	ARIMA	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	.013	.042	.033	.033
2 DAYS	.038	.063	.057	.069
5 DAYS	.092	.120	.129	.233
10 DAYS	.257	.313	.395	.909
15 DAYS	.477	.559	.838	2.442
20 DAYS	.721	.858	1.530	5.259
25 DAYS	1.032	1.200	2.546	10.141
30 DAYS	1.403	1.602	3.917	17.657

CALIBRATION INTERVAL
28 DAYS

ARIMA	2ND DEGREE	3RD DEGREE	4TH DEGREE
0.012	0.053	0.041	0.029
0.029	0.078	0.065	0.053
0.078	0.161	0.161	0.175
0.197	0.334	0.422	0.617
0.399	0.560	0.737	1.669
0.646	0.848	1.356	3.558
0.941	1.172	2.114	6.652
1.284	1.583	3.109	11.395

CALIBRATION INTERVAL
42 DAYS

PREDICTION LEAD TIME	ARIMA	2ND DEGREE	3RD DEGREE	4TH DEGREE
1 DAY	.013	.086	.087	.044
2 DAYS	.031	.114	.123	.067
5 DAYS	.094	.213	.241	.170
10 DAYS	.169	.393	.471	.478
15 DAYS	.317	.626	.720	1.163
20 DAYS	.503	.845	1.025	2.289
25 DAYS	.735	1.142	1.454	4.142
30 DAYS	1.018	1.465	1.979	6.359

CALIBRATION INTERVAL
56 DAYS

ARIMA	2ND DEGREE	3RD DEGREE	4TH DEGREE
0.016	0.132	0.085	0.066
0.035	0.159	0.107	0.100
0.093	0.244	0.188	0.226
0.239	0.439	0.356	0.628
0.416	0.648	0.577	1.306
0.633	0.907	0.878	2.301
0.872	1.191	1.230	3.721
1.223	1.541	1.715	5.838

NOTE: THE RMS PREDICTION ERRORS ARE IN UNITS OF SECONDS.

NUMBER OF SAMPLE INTERVALS

PREDICTION LEAD TIME	CALIBRATION INTERVAL 7	14	21	28	42	56
DAY 1	180	38	60	44	23	20
2	180	33	60	44	25	20
5	180	38	60	44	23	20
10	180	38	60	43	23	20
15	179	35	60	41	25	20
20	177	84	59	41	25	20
25	175	84	57	41	24	20
30	173	33	55	41	23	17

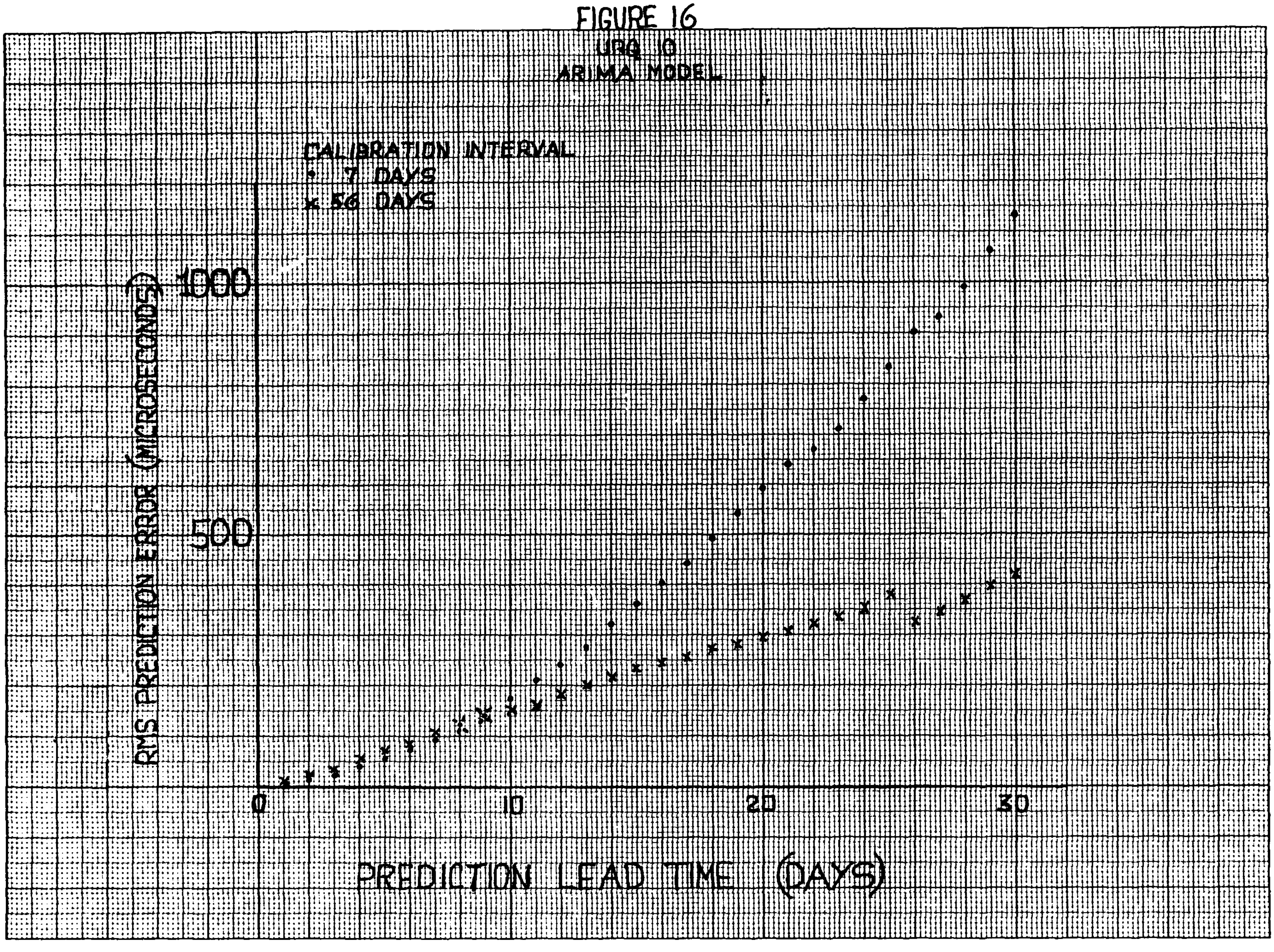
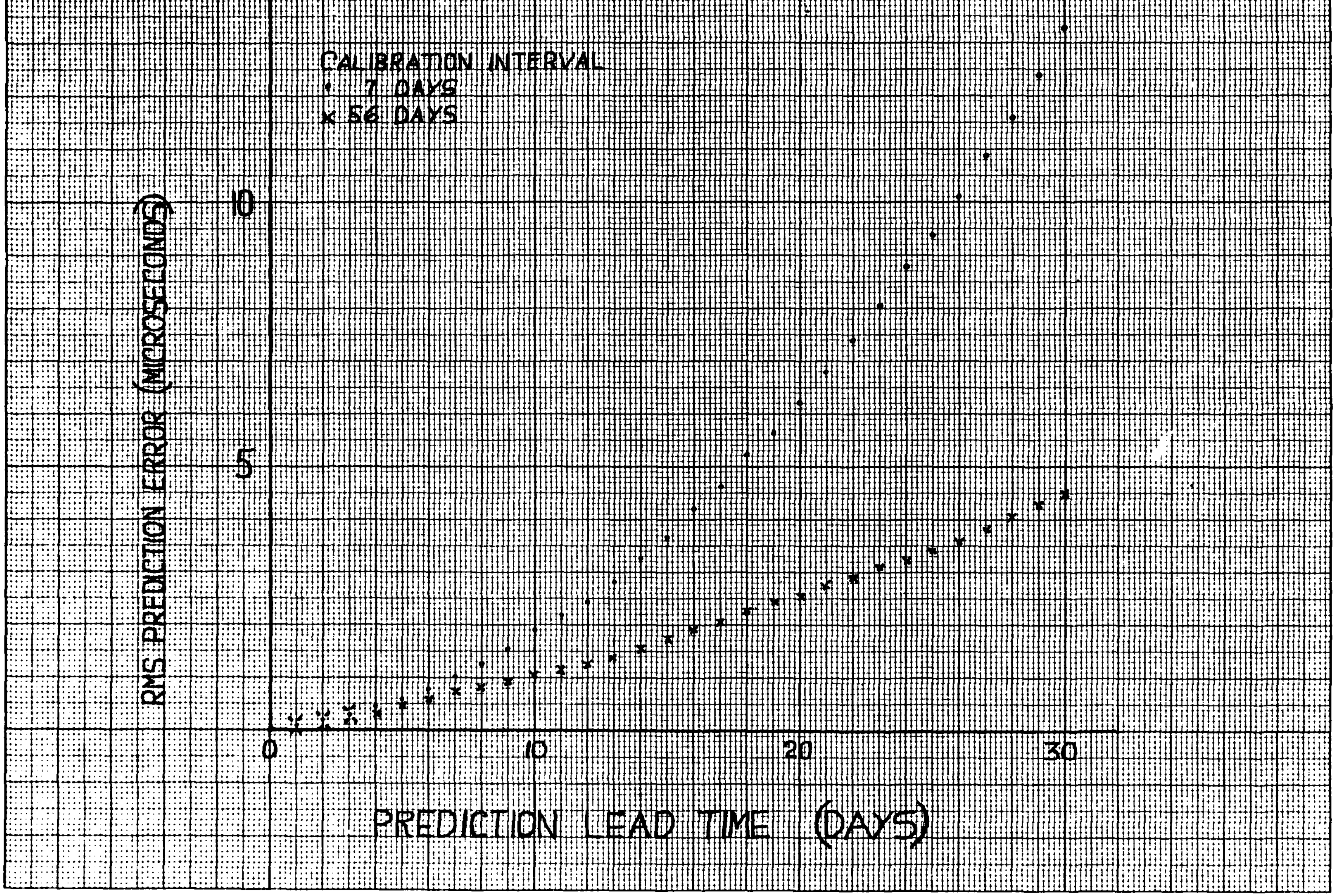


FIGURE 16
URQ 10
ARIMA MODEL
CALIBRATION INTERVAL
• 7 DAYS
x 56 DAYS
RMS PREDICTION ERROR (MICROSECONDS)
1000
500
0
10
20
30
PREDICTION LEAD TIME (DAYS)

FIGURE 17
HP 236 RUBIDIUM
ARIMA MODEL



Appendix A.1

DISCIPLINED TIME FREQUENCY OSCILLATOR*

TECHNICAL SPECIFICATIONS

OUTPUT SIGNALS

FREQUENCIES

Sine Wave:	5 MHz, 1 MHz
Square Wave:	100 kHz
Pulse:	1 PPS, 1MPPS

LEVELS:

Sine Wave:	1.0 Vrms ±20% into 50 ohms
Square Wave:	TTL compatible, 50% duty cycle
Pulse:	
1 PPS:	+4.7 V ±10% into 50 ohm, 20 usec. wide. Rise time less than 10ns. Jitter less than 100ps (unsynchronized)
1 MPPS	0.2 usec. wide, negative going, TTL compatible

STABILITY (5 MHz):

AVERAGING TIME:	
100 usec.	3 PP10^{9}
1 msec.	4 PP10^{10}
10 msec.	5 PP10^{11}
100 msec.	6 PP10^{12}
1 sec.	2 PP10^{12}
10 sec.	2 PP10^{12}
100 sec.	3 PP10^{12}
24 Hours:	3-5 PP10^{11}
Under shock (MIL-E-16400)	2 PP10^{9}
Temperature (0° to +50°C)	2 PP10^{10}
Orientation	$\Delta f/f$ ±5 PP10^{10} max at ±45°

ISOLATION: All outputs short circuit proof.
1 PP 10^{11} freq change no load to full load.

SPECTRAL PURITY:

Harmonics: <—40 dB
Spurious: 5 MHz, 1 MHz<—110 dB

Noise: Frequency From Carrier	Single Sideband Noise (dB/Hz). Referenced to Carrier: 5 MHz	1 MHz
10 Hz	—130	—135
100 Hz	—140	—140
1 kHz	—160	—145
10 kHz	—165	—150

WARM-UP CHARACTERISTIC (at +22°C)

To lock	<1 hour
To 5 PP10^{11}/day	<11 days

OSCILLATOR ADJUSTMENT

Coarse Adj. Range:	1 PP 10^{7}
Fine Adj. Range:	Digital Indicator 0 to 999 in PP10^{11}

PHASE LOCK FUNCTIONS

INPUT FREQUENCIES:	
5 MHz	1-10V PP
1 MHz	1-4V PP
INPUT IMPEDANCE:	>1000 ohms
RESOLUTION (With Memory):	± 2.5 PP10^{12}
PHASE LOCK LOOP FILTER:	
Time Constant:	100 sec. or 1 sec., switch selectable.
Control Range:	± 1 PP10^{8}
UNLOCK DETECTOR:	Responds to loss of input signal level, phase detector slippage, or loss of internal reference
LOCK ACQUISITION:	Manual control.

1 PPS GENERATOR

SYNCHRONIZATION INPUT:

a) 1 PPS, 1-10V PP width >5 usec.
b) 1 PPS +1 MHz (Algebraically added) equal amplitudes of 1-3V PP, pulse width >5 usec.
c) Sync Pulse Rise Time: 0.1 usec. maximum

Synchronization Delay:	0.5 usec. min., 0.25 usec. max.
Synchronization Mode:	a) Continuous (Syncs to every input pulse) b) Intermittent (Syncs to first pulse after switch is thrown)

POWER REQUIREMENTS:

AC:	115 Vac ±10%, 50-400 Hz, single phase (15 watts nominal) 28 watts max.
External DC:	+22 to +30 Vdc (12 watts nominal) 26 watts max. (cold start)
Internal Battery Capacity:	7 hours at +22°C (automatic recharge)

*Excerpt from Reference 7

CIRCUIT CHECK FUNCTIONS

TEST METER/SWITCH	Front Panel Switch; 12 Positions 5 MHz output 1 MHz output 100 kHz output Memory Voltage 5 MHz or 1 MHz Reference Input Battery Charge/Discharge Current Battery Voltage +10 VDC DC Input Outer Oven Monitor Regulator Voltage Inner Oven Monitor

CONNECTORS

Front and Rear:	5 MHz, 1 MHz, 100 kHz, 1 PPS (BNC)
Front Only:	1 PPS sync input (BNC) 5 MHz lock input (BNC)
Rear Only:	1 MHz +1 PPS sync and lock input, 1 MPPS output, (BNC) EXT. DC input. (MS 3102E-10SL-3P)

ENVIRONMENTAL

Humidity:	95% RH
Altitude:	0 to 15,000 ft.
Operating Temperature Range:	0°C to +50°C (Navy Class 3)
Shock & Vibration:	Per MIL-E-16400 (Note: to MIL-E-5400 optional)
EMI	Meets MIL-STD-461, MIL-STD-462.

MECHANICAL

Portable:	Carrying handle integral to case.
Housing Dimensions:	12" long x 5½" wide x 7¾" high
Weight w/Batteries:	23 pounds

OPTIONS:

1) Phase lock input for 1/N MHz rate, all integral submultiples of 1 MHz from 500 kHz down to 1 Hz.
2) Other operating temperature ranges (−54°C to +65°C, −40°C to +55°C, +15°C to +35°C, Navy classes 1, 2, 4 respectively).
3) 10 minutes warmup to lock.
4) DTF Module FE 150A may be ordered separately for OEM users (See outline drawing for installation details).
5) DTF without 1 PPS Generator and Frequency Control is a low noise high stability standard.
6) Additional Battery Pack for extended battery operating periods up to 24 hours.
7) MIL-E-5400 environmental specification.
8) AC failure remote alarm relay.
9) Permanent non-volatile memory for restoration of DTF accuracy after complete power failure.
10) Other output frequencies available.
11) External Memory "Hold" Control.
12) 100 MHz Output Module

APPLICATIONS:

1) Quartz Crystal Frequency and Time Standard for laboratory, factory, ground and satellite communications, air collision avoidance or navigation systems.
2) Tracking Filter — Narrowband tracking filter (1 Hz or 0.01 Hz bandwidth).
3) Time clean-up filter. Synchronized at user's option, 50 pico-sec. jitter when unsynced.
4) Portable Time/Frequency Transfer. Sync the DTF to an Atomic Standard and transport to site for transfer or comparison of time-frequency.
5) Local or remote slave clean-up oscillator for cesium beam standard provides better short term stability characteristic and spectral purity.
6) Low noise carrier generator for exciting transmitters.
7) Low-noise reference for signal measurements.
8) Redundant clock with cesium standard, two DTF's plus cesium replaces three cesium standards and comparators.
9) Terminus of TV time link where information is intermittent.
10) Terminus of microwave link where information is intermittent.
11) Observation of unfiltered phase detector output enables measurement of jitter, spurious, etc. on other equipment.
12) Portable accurate time transfer for line delay measurements.

Appendix A.2

OSCILLOQUARTZ*

3.0 Performance. Equipment performances established by this specification are minimum requirements, and any variations must only be in the direction of improved performance. The contractor is held responsible for meeting these performance requirements unless specific exception has been obtained in writing from the Contracting Officer.

3.1 Output Signals.

Sine Wave	1 MHz and 5 MHz at 1.0 V_{rms} ±20% into 50 ohms
Pulse	1 PPS at 5V PP ±20% into 50 ohms

3.2 Frequency Stability. $\frac{\Delta f}{f}$ -5 MHz Signal (Under free-running and memory conditions)

Averaging Time	$\frac{\Delta f}{f}$
10 msec	5 in 10^{11}
100 msec	6 in 10^{12}
1 sec	2 in 10^{12}
100 sec	3 in 10^{12}

Frequency Drift. After a warm-up period of 10 days, the accumulated frequency drift shall not exceed the following rates:

24 hours	1 in 10^{10}
10 days	7 in 10^{10}

Environmental Effects. The frequency errors caused by the following effects shall not exceed the following:

Temperature (0° to 50°C)	±5 in 10^{10}
Supply Voltage (115 VAC ±10%)	±3 in 10^{11}
Load Variation (50 ohms ±10%)	±5 in 10^{11}
Orientation (±45°)	±5 in 10^{10}

*Excerpt from Solicitation No. N68171-76-R-0144, 13 April 1976.

3.3 Spectral Purity.

(a)	Harmonics	5 MHz - At least 40 dB below output
		1 MHz - At least 30 dB below output
(b)	Non-Harmonic, Subharmonics, & Spurious	5 MHz - At least 110 dB below output for frequency offset greater than 1000 Hz from carrier.

(c) Single Sideband Noise (dB/Hz)

Frequency Offset from Carrier (Hz)	5 MHz	1 MHz
0.1	-71	-76
1	-101	-106
10	-130	-135
100	-140	-140
1000	-160	-145

3.4 Frequency Adjustment.

Coarse Adjustment Range	*1 in* 10^7
Fine Adjustment Range	1 in 10^8
Resolution	2 in 10^{11}

3.5 Phase Lock Function. The capability of being phase-locked to the following input reference frequencies shall be provided.

5 MHz	1 to 10V PP
1 MHz	1 to 4V PP
Input Impedance	50 ohms
Loop Filter	Time constant selectable 1, 10, and 100 seconds
Control Range	1 in 10^8
Resolution (with memory)	1 in 10^{11}
Unlock Indicator	Activated by loss of input signal, phase detector slippage, or loss of reference signal
Loop Control Voltage Indicator	To allow course adjustment of oscillator frequency

3.6 Digital Memory. Capable of maintaining the oscillator at its last phase-locked frequency for a period of at least 10 days after reference signal is lost. During the period of no reference signal, the frequency stability and spectral purity shall be as specified in Paragraphs 3.2 and 3.3 respectively. Reacquisition of phase lock shall be automatic after the reference signal is restored and shall be accomplished at a correction rate no greater than the oscillator loop time constant.

3.7 Synchronous Counter.

Output	1 PPS at 5V PP
Synchronization Input	1 PPS at 1 to 10V into 50 ohms
Synchronization Mode	Continuous (syncs to every pulse), intermittent (to first pulse)
Synchronization Delay	The internal 1 PPS shall be capable of being shifted in steps of 0.1 μsec maximum over a range of 10 μsec minimum.

3.8 Clock.

Time Counter

Display	Hours, minutes, and seconds
Synchronization	Internal 1 PPS operates clock and can be synchronized to external 1 PPS reference
Time Setting	Push-button for rapid time setting

Time Comparator

Display	Digital display of measured Δt
Reference Input	1 PPS, 1 to 10V PP into 50 ohms
Resolution	0.1 μsec

3.9 Power.

Primary Power	115 VAC ±10%, 50 to 400 Hz ±5%
Standby Battery Supply	2 hours at +22°C (including clock)
	Floating input
	Automatic recharge

3.10 Environmental Conditions.

3.10.1 Equipment Operating. The equipments shall meet the performance of this specification while subjected to any of the following conditions or combinations thereof:

Operation	Continuous (24 hours per day)
Temperature Range	0 to 50°C
Humidity	5% to 95% RH over temperature range
Altitude	0 to 10,000 feet above sea level

3.10.2 Equipment Non-Operating. The equipments - as packaged for storage, during transit, and in any non-operating configuration - shall be constructed to comply with the operational requirements of this specification after subjection to any of the following non-operating conditions:

Temperature	-32°C to +40°C
Altitude	0 to 40,000 feet above sea level
Salt Atmosphere	As encountered in coastal service
Shock & Vibration	As encountered in military transportation via rail, truck, or fixed-wing aircraft

Appendix B

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